FRESHWATER GROWTH AND RECRUITMENT OF YUKON AND KUSKOKWIM RIVER CHINOOK SALMON: A RETROSPECTIVE GROWTH ANALYSIS

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A

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## Abstract

Chinook salmon *Oncorhynchus tshawytscha* recruitment in the Yukon and Kuskokwim (Y-K) region of western Alaska is important for subsistence and commercial harvest. Recruitment of Chinook salmon in this region has been unpredictable in recent years, and managers and subsistence harvesters are searching for answers. Chinook salmon require freshwater growth to smolt, and larger smolts are thought to have higher marine survival. In this study, I tested for correlations between freshwater growth and recruitment using measurements from scale digitizations. All analyses were conducted at the tributary scale, with one tributary representing each river system. Linear regressions were used to check for correlations between freshwater growth and Chinook salmon returns (female productivity – recruits per spawner), number and size of female spawners present, marine growth, and water temperature. Tukey multiple comparison tests and stacked bar plots were used to check for correlations between freshwater growth and the age at which females mature and between freshwater growth and early maturation. I found no direct correlation between freshwater growth and recruitment in either tributary. However, freshwater growth appears to be decreasing as time progresses. These results suggest that, while important, freshwater growth is not the factor directly limiting recruitment in either of these tributaries.

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# 1 Introduction

## *1.1 Background*

Chinook salmon *Oncorhynchus tshawytscha* recruitment in the Yukon and Kuskokwim (Y-K) region of western Alaska is important for subsistence and commercial harvest, but has been unpredictable in recent years. Over half of the total annual statewide subsistence harvest of Chinook salmon is taken from the Y-K region (Molyneaux et al. 2010a). The Kuskokwim River subsistence fishery is one of the largest in Alaska, and Chinook salmon are the primary target salmon species (Molyneaux et al. 2005). The commercial fishing industry in this region has already been strained due to competition from farmed fish in countries such as Canada and Chile (Buklis 1999). Disaster declarations were made in the Y-K region from 1997 to 2002 due to low returns of Chinook salmon (Myers et al. 2008). Declines in Chinook salmon returns to the Y-K region have led to severe restrictions on commercial and subsistence fisheries, sometimes leading to complete closures (AYKSSI 2008). These combined factors have placed strains on commercial and subsistence salmon fishermen trying to make a living in the Y-K region. Fishery managers are particularly interested in better understanding the biology of Chinook salmon (Molyneaux et al. 2005), with the goal of managing Chinook salmon in the Y-K region more effectively to allow for sustainable harvests.

Many factors may be responsible for declines in Chinook salmon returns in the Y-K region, including growth of juvenile fish in the freshwater environment prior to migration to the ocean. Climate change is an ever-present condition that affects physical and physiological processes of fish and production of smaller prey organisms in freshwater and marine environments (Francis and Sibley 1991). Freshwater environments are less productive than marine environments at higher latitudes, such as in the Y-K region; therefore, growth in the Y-K region may be more limiting in freshwater than in the marine environment. Increasing water temperatures have been known to increase the amount of stress Chinook salmon experience in the freshwater environment through decreased dissolved oxygen levels, among other effects (Mazeaud et al. 1977). This could be affecting the amount of freshwater growth achieved by juvenile Chinook salmon in the Y-K region, which in turn could be affecting recruitment of the species.

Survival of salmon in the marine environment is thought to play a critical role in recruitment (Beamish et al. 2004). The critical-size hypothesis states that salmon year-class strength is determined in two stages during the first year of growth in the marine environment: 1) juvenile salmon that experience early mortality due to size-selective predation; and 2) juvenile salmon that fail to reach a critical size by the end of their first summer of marine growth and thus do not survive the following winter (Beamish and Mahnken 2001). It follows from this hypothesis that freshwater growth should be related to recruitment, as mortality in the early phases of marine life is thought to be size selective. Several studies on salmon have validated this assumption (e.g., coho salmon *O. kisutch*, Bradford et al. 2000; Atlantic salmon *Salmo salar*, Johnston et al. 2003; Chinook salmon, Ruggerone et al. 2009) and, in some cases, freshwater growth has been shown to directly affect recruitment (e.g., steelhead *O. mykiss*, Ward et al. 1989; coho salmon, Holtby and Scrivener 1989; Atlantic salmon, Friedland et al. 2009). Overall, these studies have found positive, negative, or no correlations between freshwater growth and recruitment, demonstrating the need for testing this correlation on a case-by-case basis.

### *1.2 Salmon Scales and Growth*

Salmon scales are read to interpret fish age and to measure variation in growth (Shearer 1992). Once scale formation begins (between 50-60 mm FL in Chinook salmon [B.

Walker, University of Alaska Fairbanks, personal communication, 2012]), growth in fish length is directly correlated with growth in scale width (Bilton 1975). Scale formation occurs from the periphery of the scale and creates scale ridges known as circuli (Fisher and Pearcy 1990). Bands of closely spaced circuli after bands of broader spacing are known collectively as checks, and those that define the boundary between years of growth are known as annuli. Freshwater (slower) growth is distinguished from marine (faster) growth by the thickness and spacing of circuli, with freshwater circuli being thinner and more narrowly spaced. The distance between the focus (or center) of a scale and the end of the freshwater growth zone is used as a proxy for freshwater growth, and, more generally, the distance between annuli serves as a proxy for each respective year's growth.

Scale reading relies on several assumptions concerning the reader, the scale, and the fish sampled. First, it is assumed that the reader read the scale accurately and was consistent in reading among scales. Second, it is assumed the scale is an accurate representative of the fish it originated from and was taken from the preferred area of the fish (Hagen et al. 2001). Third, scale analysis assumes that the fish being aged are representative of the population from which they originated. These assumptions, when met, allow for standardization of data for more accurate analysis.

Sufficient data are available for studies in Alaska and have been used in previous studies. Escapement projects (e.g., Molyneaux et al. 2008) monitored by the Alaska Department of Fish and Game (ADF&G) have collected long-term age, sex, and length (ASL) data on Chinook salmon. Chinook salmon scale data have also been collected for both the Yukon and Kuskokwim river tributaries (e.g., DuBois and Liller 2010), and these data have been used in combination to understand long-term variation in growth patterns of Pacific salmon (e.g., Ruggerone et al. 2009).

Scale-reading methods have been used to quantify freshwater growth in previous studies of Chinook salmon in Alaska. Chinook salmon scale archives from both the Yukon and Kuskokwim rivers have been used to study relationships between freshwater growth, marine growth, climate, and abundance (Ruggerone et al. 2007a, 2007b, 2009) at the regional (basin) scale. In these studies, a positive correlation between growth of an individual fish in a given year and the previous year was identified. Correlations were strongest when the previous year had low growth relative to other years. Females were found to attain greater size than males and individuals that returned to spawn in three versus four years exhibited faster growth rates. Those differences in growth rate between age classes were not consistent between river systems, with growth diverging later (during the marine period) in the Kuskokwim River and earlier (during the freshwater period) in the Yukon River (Ruggerone et al. 2007a). Reasons for differences have not been identified, but may be attributed to differences in river systems, such as habitat availability and habitat quality.

Although previous studies have addressed the correlation between growth and abundance in Y-K Chinook salmon, there are some aspects that require further attention. For the purposes of my study, samples were examined at the tributary level to examine the relationship between freshwater growth and recruitment acting at the population level. To account for the effect of freshwater growth on overall body size, scale circuli width was measured from scale samples. My study also included all age classes when possible to view the effect of recruitment across all ages and between generations. Differences in spatial scale, freshwater growth variables, and the age classes included distinguished my study from previous studies and provided opportunities for new insights. Data from my study were used to determine direct effects of growth on recruitment, as well as indirect effects, possible variables affecting freshwater growth, and effects of freshwater growth on life-history aspects. My study was important to management of Chinook salmon in the

Y-K region because data collected and analyzed provides information to managers that can be used to direct future management.

### *1.3 Objectives*

The overall goal of this study was to determine if freshwater growth was correlated with recruitment of Chinook salmon in the Yukon and Kuskokwim rivers. Specific objectives were to:

1. Test for evidence of a minimum size necessary for smolts to survive to maturity.
2. Test for a correlation between freshwater growth and female productivity (number of returning females per spawner).
3. Test for a correlation between freshwater growth and the age at which females mature.
4. Test for a correlation between the size and the number of females and the freshwater growth of their offspring.
5. Test for a correlation between marine growth and freshwater growth.
6. Test for a correlation between water temperature and freshwater growth.

In my study, scale circuli increment widths were used as an index of growth, similar to Ruggerone et al. (2007a, 2009), and scale circuli increment widths were used to determine the importance of freshwater processes on recruitment of Chinook salmon in the Yukon and Kuskokwim river systems. Analyses were conducted at the tributary scale instead of at the regional scale because the finer spatial resolution allowed for tracking the effects of freshwater growth on recruitment within populations. Freshwater growth was tested for a direct correlation with recruitment in terms of female productivity (recruits per spawner). Marine growth in each population, and the extent to which it was related to freshwater growth, was examined following Ruggerone et al. (2009) to see if their previous results were upheld at the tributary level and to test for an indirect correlation between freshwater growth and recruitment. I examined water temperature and density dependence (in terms of size and number of females and freshwater growth of their offspring) to determine their effects on freshwater growth. Freshwater growth was tested for correlations with female age-at-maturity and minimum smolt size to determine freshwater growth effects on life-history attributes. In addition, a correlation between marine growth (SW1) and the number of females returning to spawn was tested. The results from my study could provide direction for future management of Chinook salmon in the Y-K region, whether that is towards the freshwater environment or the marine environment, based on possible direct and indirect correlations between freshwater growth and recruitment.

## 2 Methods

### *2.1 Chinook Salmon Sampling*

Two tributaries, the Andreafsky River from the Yukon drainage and the Kogrukluk River from the Kuskokwim drainage, were chosen for my study (Figure 1). Both tributaries support spawning populations of Chinook salmon, have long-term escapement projects (weirs) in place, and have long-term scale archives available. The Andreafsky River is a large tributary of the Yukon River located 167 km upstream of the mouth of the Yukon River (Clark 2001), while the Kogrukluk River is a tributary of the Kuskokwim River located 724 km upstream of the mouth of the Kuskokwim River.

Chinook salmon were collected for biological sampling differently in each system. In the Andreafsky River, the sample size necessary for each year was determined by a stratified random sampling design (Cochran 1977). Andreafsky River Chinook salmon were collected by funneling fish into a live trap placed on the left side of the river (Maschmann 2011). The Kogrukluk River sample size was determined following conventions described by Bromaghin (1993), which allow for smaller sample sizes due to fixed individual confidence levels, to achieve simultaneous 95% confidence intervals of age-sex composition no wider than ±10% ($\alpha = 0.05$). Kogrukluk River Chinook salmon were "actively sampled", which consisted of being caught individually while they passed through the weir. Sample sizes for both tributaries were increased by 20 percent to account for unreadable scales or collection errors.

Chinook salmon were sampled for age, sex, and length composition data in the same manner, regardless of tributary.  Three scales were collected from each fish and were used to determine the age of each individual. Sex was determined visually by secondary sexual characteristics, focusing on prominence of a kype (snout), roundness of the belly, and the presence/absence of an ovipositor (egg-deposition organ in females; Williams and Shelden 2010). Mid-eye to fork of caudal fin length was measured and rounded to the nearest 5 mm for the Andreafsky River (Maschmann 2011) and measured to the nearest 1 mm in the Kogrukluk River (Williams and Shelden 2010). These results were recorded onto computer spreadsheets for exportation into system databases (Williams and Shelden 2010).

Scales were collected from the “preferred area” of the fish, which is located on the left side of the body, on a diagonal line from the posterior region of the base of the dorsal fin to the posterior region of the anal fin, and two rows above the lateral line (Hagen et al. 2001). Scales were placed on gum cards and kept in scale archives with ADF&G in Anchorage. Acetate impressions were made in order to work with scales without risking damage to the original samples.

Chinook salmon scale archives for my study were acquired from ADF&G in Anchorage. Both river systems’ scale collections contain at least 30 years of scale data. Brood years from the 1970s were not used in most analyses because few scales were available. Scales were collected from the Andreafsky River weir consistently from 1980 to 2010, excluding 2006 (missing). Scales were collected from the Kogrukluk River weir consistently from 1981 to 2010, with an additional year of data in 1978. Acetate impressions of these scales were made and shipped to Juneau to be digitized at the ADF&G Mark, Tag, and Age Laboratory.

### *2.2 Scale Reading*

The scale sampling goal for this study was 25 females per age/year because this sample size has been shown to be adequate to capture the variability in a given year class and is the standard for the ADF&G Mark, Tag, and Age Laboratory (B. Agler, ADF&G, personal communication, 2010). All scales available for each age class per year were assessed for quality because in most years scale collections for each tributary contained 25 or less scales for each represented age class. Only females were analyzed because female Chinook salmon have a larger impact on the initial number of offspring produced (via number of eggs), and because the relationship between body size and reproductive success with females is more straightforward than for male Chinook salmon. For example, female Chinook salmon have been shown empirically to have a linear relationship between length and fecundity, with larger females depositing more eggs (Quinn 2005). This is not the case for male Chinook salmon, with males varying in the amount of investment in mate competition which affects reproductive success (Kinnison et al. 2003). Reproductive success in males depends heavily on the ability to acquire mates, but this is not linearly related to body size (Fleming and Gross 1994, Quinn and Foote 1994, Kinnison et al. 2003). Male Chinook salmon display more age classes at maturity than female Chinook salmon due in part to the non-linear relationship between reproductive success and body size (Quinn 2005). Therefore, limiting analyses to female fish also simplified data analysis.

Scale impressions were viewed on a microfiche reader and compared to accompanying ASL data to determine if the previous age assignments agreed with what was being read. Scale-selection criteria were determined according to Hagen et al. (2001). A scale was selected for digitization if: 1) the circuli and annuli were clearly defined; 2) the scale reader agreed with the age recorded previously by a trained ADF&G reader; and 3) the scale could be read efficiently. Scales were discarded if: 1) accompanying data did not match the scale being viewed; 2) the scale impression quality was poor; 3) the scale pattern itself was unusual and could not be read with confidence by the reader; 4) the scale was determined to be regenerated; or 5) the scale edge showed significant resorption. Moderately suitable scales were included if necessary to achieve minimum sample size. A scale was considered moderately suitable if the scale impression quality was poor but two trained scale readers (myself and an ADF&G reader) could read the scale efficiently.

Scales selected for analysis were digitized by following the semi-automated image analysis routine outlined by Hagen et al. (2001). A high-resolution line camera, Screenscan® Microfiche Scanner (Salem, Wisconsin), was attached to a microfiche reader and a Windows PC computer. This allowed for pictures to be taken directly off the microfiche reader. Scale images taken were stored as Tagged Image File Format (TIFF) files at 8-bit depth and at 3353 x 4425 pixels, which created an uncompressed file size of 14.5 Mb per scale. High resolution scale images allowed the entire scale to be viewed for aging, as well as accurate measurement of circuli spacing.

It is important to clarify the data that are being collected from the digitization of scales. Growth determined from scales is not actual growth in body size, but rather an indicator used to infer the magnitude of fish growth. Salmon scale measurements are referred to as increment widths, with freshwater increment width referring to freshwater scale growth and saltwater increment width referring to marine scale growth. Within types of increment widths, zones of growth are separated by year of growth (e.g., FW1 for freshwater growth zone 1 – first year freshwater growth, SW1 for marine growth zone 1 – first year marine growth, etc.). Chinook salmon scales have been analyzed similarly in similar studies (Ruggerone et al. 2007a, 2007b, 2009).

Scale images were digitized (where growth zones were delineated and then measured) using ImagePro® 7.0 Image Analysis Program (Acton, Massachusetts). Images were loaded into this system and digitized using an unpublished macro developed by ADF&G. Digitization occurred along the longest radius of each scale according to a digitization protocol established by the ADF&G Mark, Tag, and Age Laboratory. Scale digitization consisted of defining all annuli (freshwater growth zone 1 [FW1], marine growth zone 1 [SW1], marine growth zone 2 [SW2], etc.) and freshwater plus growth ([FW+] – freshwater growth put on following the first winter in freshwater; Ruggerone et al. 2007a). Circuli were considered the dark portion (rings) of each scale, and were measured by identifying the outermost portion of the circulus from the focus of the scale to the outermost portion. Distances between marked circuli and between annuli were recorded in µm.

Throughout the remainder of this thesis, the scale measurement used to infer freshwater growth will be referred to as freshwater increment width. Freshwater increment widths in the first year are referred to as FW1 and freshwater increment widths after FW1 are referred to as FW+. Throughout the remainder of this thesis, the scale measurement used to infer marine growth will be referred to as saltwater increment width, and zones of growth will be referred to in the same manner as freshwater increment width (SW1, SW2, SW3, SW4, SW5, and SWALL – all marine growth). All corresponding growth zones were quantified as the distance from the previous annulus to the next annulus measured in µm.

Once each system's scale data was digitized, it was imported into its own Microsoft Access® Database (Redmond, Washington) using a program developed by the ADF&G Mark, Tag, and Age Laboratory. Microsoft Access® allowed for separation of data for analysis. From this point, data was exported into Microsoft Excel® (Redmond, Washington) to be analyzed in the statistical program R (R Development Core Team 2009).

### *2.3 Smolt Minimum Size to Survive to Maturity*

The existence of minimum sizes necessary for smolts to survive to maturity was determined by assuming that freshwater growth for each Chinook salmon brood year was normally distributed prior to any size-selective mortality. Mortality of smaller fish was expected to truncate the lower tail of the freshwater growth distribution, leading to non-normality. Therefore, brood years that were determined to have left-truncated, non-normal distributions were considered evidence for a smolt minimum size to survive to maturity.

Distributions of FW1 were tested by brood year for deviations from a normal distribution by performing the Shapiro-Wilk test (Shapiro and Wilk 1965), with further interpretation of these results conducted through Q-Q plots (Wilk and Gnanadesikan 1968). For my purposes, sample data were compared to a statistical population representing a normal distribution (Wilk and Gnanadesikan 1968). Both minimum and mean FW1s were determined for each brood year of scale data for both rivers.

In addition, minimum FW1 was examined for every brood year for both tributaries. Ranges of annual minimum FW1 were calculated for each tributary as well. Finally, average minimum FW1 was calculated by tributary across all brood years.

### *2.4 Correlation Between Freshwater Growth and Female Productivity*

Brood tables were constructed to estimate female brood return (FBR) as the total number of returning offspring that were female. Female brood return was used to determine whether or not a correlation existed between freshwater growth and female productivity (FBR per spawner).

Both tributaries' brood tables took into account harvest, escapement, age composition, and sex composition data. The years 1985 to 2002 were included in the Andreafsky River brood tables and the years 1986 to 2002 were included in the Kogrukluk River brood tables because these were the years that contained the most consistently collected data. The years 2003-2010 were not included because all age classes from those brood years had not yet returned to spawn. The brood table consisted of summed escapement and harvest estimates, where escapement estimates for both tributaries were taken from weir counts. Both escapement and harvest estimates were broken down into age composition, which ranged from ages 1.1 to 1.6 (Tables 1 and 2). Age and sex composition estimates were acquired from ASL data for each escapement project, with the Andreafsky River acquired from an ADF&G Fisheries Biologist for the Yukon Area, Kyle Schumann, and the Kogrukluk River acquired from Molyneaux et al. (2010b).

Total escapement estimates were multiplied by female percent composition and female age composition estimates to estimate the age class-specific number of females in every year. Brood years were determined for escapement data from the number of fish in a given age class and the number of females returning every year. The brood year of a given age class of fish was calculated as follows: brood year = year collected - (years in freshwater + years in marine + 1 for time spent in gravel as an egg). For example, for a

1.2 age fish collected in 1992, brood year = 1992-(1+2+1) = 1988. All fish back-calculated to the same brood year were summed to determine every brood year's female escapement.

Andreafsky River harvest estimates were taken as a percentage of overall Yukon River total harvest estimates as given in Spencer et al. (2009). Harvest of the Andreafsky River was thought to be only 2.2% of the total Yukon River harvest (Spencer et al. 2009). Harvested fish were assumed to have the same age and sex composition as escapement estimates. Assignment of harvest estimates (commercial, subsistence, and sport harvest) to brood years was calculated in the same manner as for escapement data. Harvests of females from the same brood year were summed together to determine total female harvest for every brood year.

Kogrukluk River harvest estimates were calculated as proportions of the total number of fish harvested in commercial, subsistence, sport, and test harvest fisheries in both the upper and lower Kuskokwim River. Of fish tagged in the lower river, the percentage of upper Kuskokwim River fish was assumed to be 71.5 %, the average percentage observed in tagging studies conducted from 2003-2007 (Schaberg et al. 2012). This mark-recapture study also estimated the proportion of fish reaching the upper Kuskokwim River that were destined for the Kogrukluk River, which averaged 9.4% over the years 2002-2007. Thus, 9.4% of upper river harvests were assigned to the Kogrukluk River, while the proportion of lower river harvests assigned was 71.5% x 9.4%. Harvest estimates were assumed to have the same age and sex composition as escapement estimates because no stock-specific age and sex composition was available. These estimated harvests were assigned to brood years in the same manner as escapement data. Total numbers of fish from the same brood year were summed to determine female harvest for every brood year.

Both escapement and harvest components for each brood year were summed to calculate total FBR. Stock productivity (female recruits per spawner) was calculated by dividing FBR (female recruits) by the total escapement (number of male and female spawners) that produced each brood year. Mean annual FW1 was calculated by weighting the mean FW1 of each age class by the number of female recruits in that age class.

I regressed (Kutner et al. 2004) female productivity (number of returning females per spawner) on FW1, then performed a one-tailed test on the slope to determine whether there was a significant positive relationship. Recruits per spawner by brood year for each tributary were log-transformed to maintain normality and homoscedasticity assumptions (refer to Table 3 for all following data transformations). Significance was assessed at the 95% confidence level ($p < 0.05$).

### *2.5 Correlation Between Freshwater Growth and the Age of Females Returning to Spawn*

I tested for a correlation between freshwater growth and age-at-maturity for the main age classes, 1.3, 1.4, and 1.5. I also tested for possible correlations between FW1 and early maturation, defined as number of age class 1.2 individuals. Tukey multiple comparison tests were performed to determine if different age classes displayed different amounts of FW1. Stacked bar plots were also generated for both tributaries in order to graphically display the relationship between freshwater growth and age-at-maturity. Due to possible inaccuracies in sex identification (L. DuBois, ADF&G, personal communication, 2011) of 1.2 age Chinook salmon in the Andreafsky River, a stacked bar plot excluding 1.2 females was also generated.

### *2.6 Correlation Between Number of Eggs Deposited and Freshwater Growth*

I also tested for a correlation between the number of eggs spawned and freshwater growth. Length-fecundity relationships for each river system were used (Skaugstad and McCracken 1991 for the Andreafsky River and Harper 2010 for the Kogrukluk River) to calculate the fecundity (number of eggs) of female Chinook salmon from each tributary. The numbers of eggs deposited in each brood year were calculated in the same manner for both Andreafsky and Kogrukluk rivers, based on previously constructed brood tables (see section 2.4). For each brood year, FBR was parsed by age class and then multiplied by average age class fecundities as estimated by length-fecundity relationships and average female size per age class. The resulting total eggs per brood year age class were summed across female age classes to determine total eggs per brood year.

I regressed (Kutner et al. 2004) mean FW1 on the number of eggs spawned, then performed a two-tailed test on the slope to determine whether there was a significant negative relationship. Mean FW1 for each brood year for the Andreafsky River and the Kogrukluk River were transformed (raised to the one-fourth power for the Andreafsky River and the reciprocal raised to the second power for the Kogrukluk River; Table 3) to maintain normality and homoscedasticity assumptions. Model results were used to assess the significance of predictors at the 95% confidence level ($p < 0.05$).

### *2.7 Correlations Between Growth Zones*

To determine if there was a correlation between FW1 and marine growth in the first year and sequential years at sea (SW1, SW2, SW3, SW4, and SW5), correlations were determined using Pearson's product-moment correlation coefficient (Soper et al. 1917).

I regressed (Kutner et al. 2004) every year's growth on the year of growth previous to it, then performed a two-tailed test on the slope to determine whether there was a significant positive relationship. No transformations were required to maintain normality and homoscedasticity assumptions. Model results were used to assess the significance of predictors at the 95% confidence level ($p < 0.05$).

### *2.8 Correlation Between Marine Growth and Female Productivity*

Female brood return from constructed brood tables was used to determine whether or not a correlation existed between marine growth and productivity. I regressed (Kutner et al. 2004) female productivity (number of returning females per spawner) on SW1, then performed a one-tailed test on the slope to determine whether there was a significant positive relationship. Productivity for each tributary was log-transformed in order to maintain normality and homoscedasticity assumptions. Model results were used to assess the significance of predictors at the 95% confidence level ($p < 0.05$).

### *2.9 Correlation Between Water Temperature and Freshwater Growth*

Only water temperature data for fully constructed brood years was collected because these years contained minimum FW1 and mean FW1 that were calculated with all possible age classes. Water temperature data for the Andreafsky River was acquired from the United States Geological Survey (USGS). Data was collected from Pilot Station, Alaska, located 17.7 km east of the Andreafsky River because this was the closest location with long-term water temperature data. Twelve years of water temperature data were collected and included 1985-1990, 1992-1996, and 2002 (missing data). Water temperature data for the Kogrukluk River was acquired from ADF&G. Thirteen years of water temperature data were collected and included 1988-2002, with the exception of 1989 and 1993 (missing data). Mean water temperatures were calculated by averaging daily temperatures (June water temperatures for Andreafsky River and July 6-August 31 water temperatures for Kogrukluk River) for each year at each tributary.

I regressed (Kutner et al. 2004) minimum and mean FW1 on water temperature, then performed a two-tailed test on the slope to determine whether there was a significant negative relationship. Minimum FW1 and Mean FW1 for each brood year for both tributaries was transformed (Minimum FW1 – the reciprocal raised to the second power for the Andreafsky River and the reciprocal raised to the third power for the Kogrukluk River, Mean FW1 – raised to the third power for the Andreafsky River and the reciprocal raised to the third power for the Kogrukluk River; Table 3) to maintain normality and homoscedasticity assumptions. Model results were used to assess the significance of predictors at the 95% confidence level ($p < 0.05$).

# 3 Results

## *3.1 Scales Read*

I digitized 2,971 scales for this project: 1,491 from the Andreafsky River and 1,480 from the Kuskokwim River. These scale digitizations represent data from 1980-2010, with the exception of 2006 (missing) for the Andreafsky River, and 1978 and 1981-2010 for the Kogrukluk River (Appendix I). Databases were compiled and archived at the ADF&G Mark, Tag, and Age Laboratory in Juneau for further use. The acetate impressions created for this study were also archived there for future scale work.

## *3.2 Smolt Minimum Size to Survive to Maturity*

For both rivers, there was minimal evidence for a minimum FW1 above which smolts were able to survive. Shapiro-Wilk tests and associated p-values suggest that the data were normally distributed for most brood years for both Andreafsky and Kogrukluk rivers (Table 4). The Q-Q plots suggested normal distributions for most brood years of both tributaries (Appendix II). The Andreafsky River showed non-normal distributions for brood years 1974 ($p = 0.0058$) and 1996 ($p = 0.0006$), while the Kogrukluk River showed non-normal distributions for brood years 1978 ($p = 0.0046$), 1979 ($p < 0.0001$), 1982 ($p < 0.0001$), 1993 ($p < 0.0001$), and 1997 ($p = 0.016$). A Shapiro-Wilks test could not be conducted on the brood year 1970 ($n = 1$) for the Kogrukluk River due to a small sample size. Non-normal distributions accounted for less than 17% of all brood years for both tributaries.

Andreafsky fish had a larger minimum FW1 than fish from the Kogrukluk River. The minimum FW1 for the Andreafsky River was found to be 0.202 µm (brood year 2004), with a range from 0.202 to 0.571 µm (Table 4) and an average minimum FW1 across brood years of 0.25 µm. The minimum size for the Kogrukluk River was found to be 0.168 µm (brood year 1989), with a range from 0.168 to 0.743 µm, and an average minimum FW1 across brood years of 0.228 µm. The Andreafsky River showed more variability in FW1 by brood year than the Kogrukluk River, with the Andreafsky River displaying a larger range of mean FW1 (0.302 to 0.426 µm) than the Kogrukluk River (0.27 to 0.378 µm).

Both systems showed different results between minimum FW1 and brood year, with decreasing minimum FW1 with brood year for the Andreafsky River ($p = 0.0076$) and no change in minimum FW1 with brood year for the Kogrukluk River ($p = 0.3503$; Figure 2). The same results were found between mean FW1 and brood year for both tributaries, with decreasing mean FW1 with brood year ($p = 0.025$ for Andreafsky River and $p = 0.0093$ for Kogrukluk River; Figure 3). Minimum and mean FW1 displayed notable decreases at the point which brood years would have begun contributing to the stock crash years of 1997-2002. The Andreafsky River was determined to have a stronger relationship between mean FW1 and brood year than the Kogrukluk River, with $R^2$ values of 0.372 and 0.277, respectively. The amount of decline in mean FW1 was found to be approximately the same for both rivers when the same periods of time were examined.

It is important to note that results of minimum FW1 may be affected by chance sampling and should not be over-interpreted. Minimum FW1 was included as another means to test for correlations between freshwater growth and brood year.

### *3.3 Correlation Between Freshwater Growth and Female Productivity*

There was no correlation between FW1 and productivity for either tributary (Figure 4). The Andreafsky River ($R^2$ = 0.0017, p = 0.454) showed fluctuations in FW1 that did not produce proportional increases in recruits per spawner for most brood years (Figure 5). The Kogrukluk River ($R^2$ = 0.0169, p = 0.3629) also showed fluctuations in FW1 that did not produce proportional increases in recruits per spawner for most brood years (Figure 6).

### *3.4 Correlation Between Freshwater Growth and the Age of Females Returning to Spawn*

The two rivers showed differing relationships between the amount of FW1 and the age at which females mature. Averaged over all years, fish that matured early (1.2) tended to have a smaller FW1 (0.3480 µm) than fish that matured later (age 1.3 – 0.3638 µm and age 1.4 – 0.3629 µm) in the Andreafsky River; there was no difference between the oldest (1.5 – 0.3630 µm) maturing fish and any other age fish. In the Kogrukluk River, fish that matured early had the same FW1 (age 1.2 – 0.3239 µm) as fish that matured later (age 1.3 – 0.3275 µm, 1.4 – 0.3278 µm, 1.5 – 0.3224 µm; Table 5).

Neither tributary showed obvious correlations between freshwater growth and the proportions in the main ages-at-maturity proportions (Figures 7 and 8). The stacked bar plot of the Andreafsky River without the 1.2 age class yielded no additional information (Figure 9). It is important to note that both systems contained low numbers of age 1.2 females (n = 165 for Andreafsky River and n = 16 for Kogrukluk River).

### *3.5 Correlation Between Number of Eggs Deposited and Freshwater Growth*

Both the Andreafsky ($R^2 = 0.0291$, $p = 0.4984$) and Kogrukluk ($R^2 = 0.0726$, $p = 0.2956$) rivers showed no statistically significant relationship between the total number of eggs deposited and FW1 (Figure 10), although in the Kogrukluk River the two years with the largest number of eggs both had very small FW1 values.

### *3.6 Correlations Between Growth Zones*

There was a significantly positive relationship between FW1 and SW1 for the Andreafsky River ($p = 0.0039$; Figure 11); however, the relationship was weak ($r = 0.07$; Table 6). No relationship between FW1 and SW1 was found for the Kogrukluk River ($p = 0.4684$; Figure 12). The Andreafsky River also showed weak but significant positive correlations for SW1-SW2 and SW2-SW3 (Fig. 11; Table 6), while the Kogrukluk River showed slightly stronger significant positive correlations for SW2-SW3 and SW4-SW5 (Fig. 12; Table 6).

### *3.7 Correlation Between Marine Growth and Female Productivity*

Neither river showed correlations between SW1 and productivity ($p = 0.1076$, $R^2 = 0.1885$ for Andreafsky River and $p = 0.4978$, $R^2 < 0.0001$ for Kogrukluk River; Figure 13).

### *3.8 Correlation Between Water Temperature and Freshwater Growth*

Mean summer temperature was found to have no statistically significant correlation with FW1 for either tributary. The Andreafsky River showed no correlation between minimum or mean FW1 and water temperature ($p = 0.1023$ and $p = 0.9074$; Figure 14). The Kogrukluk River showed no correlation between minimum or mean FW1 and water temperature as well ($p = 0.1764$ and $p = 0.9722$; Figure 15).

## 4 Discussion

There was no evidence from my analyses for a direct relationship between freshwater growth and recruitment in Yukon and Kuskokwim Chinook salmon. It is important to note that only one tributary was analyzed for each system and thus conclusions drawn here may not necessarily be extended to the entire Yukon and Kuskokwim river drainages. These results suggest that freshwater growth, while important for contributing to overall growth, was not a strong predictor of recruitment in these tributaries. Other implications of freshwater growth for life history and recruitment are discussed below.

### *4.1 Direct Effects of Growth on Recruitment*

In this study, no evidence for direct effects of freshwater growth on recruitment was found. The lack of a direct effect of growth on recruitment for both tributaries could be due to 1) a lack of precision in estimates of productivity and 2) other factors having a greater effect on recruitment of Chinook salmon in these tributaries.

There are many potential sources of error in the estimates of productivity and these sources of error may have obscured relationships between growth and productivity. Escapement estimates were determined in some years by sub-optimal methods. Harvest estimates were crude, and were assumed to have the same age and sex compositions as escapements, which this is likely not the case because fishing gear is size selective. There are also possible sex misidentifications that would have altered sex composition data (discussed later in 4.4). Brood tables have not been developed for tributaries in the Y-K region before because tributary-specific harvest rates have not been estimated with much certainty (Z. Liller, ADF&G, personal communication, 2013), and even estimating total return rates for entire drainages has proved challenging (Schaberg et al. 2012). Each source of error in estimates of productivity could have contributed to the lack of a direct relationship between growth and recruitment.

It is important to note that this study, which examined scales from escapement samples, as well as the study of Ruggerone et al. (2009) which used scales from in-river harvest samples, represented fish that survived juvenile – and marine – rearing phases. Size-selective mortality can result in differences in the distribution of scale growth between fish that survive and those that do not (e.g., Moss et al. 2005). Therefore, not including freshwater scale growth from fish that did not survive may also have obscured a relationship between freshwater growth and recruitment.

Finally, it is also possible that other factors have a greater impact on recruitment of Chinook salmon in these tributaries. Both freshwater and marine environmental variables have been analyzed to determine their effect on recruitment of Chinook salmon (e.g., Kope and Botsford 1990), both at local and large scales, such as at the tributary and ocean scale (Cohen et al. 1991, Pyper et al. 2005). Factors such as river discharge, water temperature, and density dependence are associated with the freshwater environment and have been attributed to recruitment of Chinook salmon (Bradford 1995, Smith et al. 2002, Achord et al. 2003) . Factors associated with the marine environment have long been attributed to recruitment of Chinook salmon and include the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (Kope and Botsford 1990). Many other factors in the marine environment have been attributed to recruitment, including changes in the ocean due to climate change, density-dependent mortality, diseases, and bycatch in other fisheries (Pearcy 1988, Walters 1988, Pearcy 1992, Upton 1992, Coronado and Hilborn 1998). Any number of these could be the limiting factors for

Chinook salmon recruitment in the Andreafsky and Kogrukluk rivers. Along with sources of error in estimates of productivity, these results could help explain the lack of a direct relationship between growth and recruitment.

### *4.2 Correlation Between Marine Growth and Freshwater Growth*

Ruggerone et al. (2009) found a positive correlation between marine growth and freshwater growth in the Yukon River at the regional scale. My results confirmed this positive correlation at the tributary scale. Possible explanations for the correlation between marine growth and freshwater growth, offered by Ruggerone et al. (2009), may apply to this study. Chinook salmon tend to select relatively large prey (Schabetsberger et al. 2003). This may in turn increase somatic growth allowing for selection of even larger prey, which could allow for somatic growth to continue increasing (Brodeur 1991). Larger body size and faster growth rates have been shown to increase survival in salmon during the first year in the marine environment and could lead to increased survival for every available year of growth (Beamish and Mahnken 2001). The mechanisms driving correlations between freshwater and marine growth at the regional level would also apply at tributary scale, which could explain positive correlations between marine growth and freshwater growth.

### *4.3 Direct Effects on Freshwater Growth*

While I did not detect a direct relationship between freshwater growth and recruitment, declining minimum and mean freshwater growth with brood year (especially brood years that contributed to stock crash years of 1997-2002) suggests than an on-going decline in freshwater growth may be contributing to recent declines in run size. Freshwater growth and recruitment data from 2003-2010 were available, but could not be used because all fish from these brood years had not yet returned. Inclusion of these data might have changed results of this study. Reduced freshwater growth might be attributed to less favorable growth conditions in the freshwater environment created by climate change and/or density dependence. Salmon life histories have adapted to local environmental conditions, which are intimately linked to climate (Crozier et al. 2008). Climate change in Alaska has produced warmer temperatures (Parmesan 2006), which have increased water temperatures, potentially creating less favorable freshwater growth conditions for populations adapted to lower temperatures (McCullough 1999). Warmer temperatures may be affecting freshwater growth conditions indirectly (Edmundson and Mazumder 2001), possibly through asynchrony between Chinook salmon and their food sources (match-mismatch hypothesis; Cushing 1990) or directly through an imbalance in metabolic demands and feeding rates (Welch et al. 1998). While a significant correlation between water temperature and freshwater growth was not detected, this result may be due to limitations of the data or analyses performed (discussed further in this section). If true, Chinook salmon may not be growing in the freshwater environment as well as in previous years because of direct and/or indirect effects from water temperature. This could explain the decreases in both minimum and mean freshwater growth for both tributaries.

Although density dependence can decrease freshwater growth, it does not appear to be a limiting factor in either of the tributaries in this study. The lack of evidence for density dependence for the Andreafsky River could be due to alternative rearing strategies and small number of Chinook salmon returns. The primary density-dependent factor is often intraspecific competition for resources, which is most evident at high population densities (Jonsson et al. 1998). Many species in the Yukon River drainage, including Andreafsky River Chinook salmon, are stocks of concern because of declines in returns (Lingnau and

Bergstrom 2003). Small numbers of Chinook salmon returns would suggest that Andreafsky River Chinook salmon populations are not susceptible to density dependence. In addition, alternative rearing strategies that use different habitats or the same habitats for shorter periods of time (e.g., nomad Chinook salmon) could allow the Andreafsky River to sustain higher numbers of fish, lessening density-dependent effects. In comparison, more evidence for density dependence for the Kogrukluk River could be due to limited habitat and/or greater number of Chinook salmon returns. The Kogrukluk River is at the upper reaches of and is one of the most remote tributaries in the Kuskokwim River system (Williams and Shelden 2011). In some cases, tributaries in upper reaches of river systems have been found to have less suitable or available habitat for Chinook salmon (e.g., Mossop and Bradford 2004). The Kogrukluk River also appears to support a relatively large number of spawning Chinook salmon compared to other Kuskokwim River tributaries of similar size (Molyneaux and Brannian 2006). Both the possibility of less habitat and greater numbers of returns could create a greater density-dependence effect in the Kogrukluk River. It is important to keep in mind that the correlation for the Kogrukluk River is largely driven by two high escapement years in the data set; as such, it is important to not over-interpret this result.

The lack of a correlation between water temperature and freshwater growth for either tributary could be due to several reasons. First, there simply may be no relationship correlation between water temperature and freshwater growth for either tributary. However, temperature is an important factor in growth of most fishes and the lack of a relationship between freshwater growth and water temperature seems unlikely. Second, and more likely, is that available water temperature data were not accurate enough to detect a correlation between water temperature and freshwater growth. Water temperature data for the Andreafsky River was from Pilot Station, Alaska, which is located 17.7 km away from the Andreafsky River and most likely is not an accurate representation of the Andreafsky River. It is possible that if Andreafsky River weir temperature data had been available and both weirs had had more consistent data, a correlation between water temperature and freshwater growth could have been found. Third, and also likely, is that using mean summer water temperature as the predictor variable may have masked potential correlations between water temperature and freshwater growth. Early summer water temperatures may be more important than late summer water temperatures and therefore may have needed to be averaged differently. Water temperature has been analyzed in degree days in previous studies of salmonids (e.g, sockeye salmon *O. nerka*, Mathes et al. 2010; chum salmon *O. keta,* Ando et al. 2011). Analyzing water temperatures in terms of days above a certain temperature has been utilized as well (Hague et al. 2011). Future analysis could address this issue and provide further insight concerning this relationship.

### *4.4 Effects of Freshwater Growth on Life History*

Differences were detected between the Andreafsky and Kogrukluk rivers in the amount of evidence to support a minimum smolt size to survive to maturity, the occurrence of maturing early, and variation in freshwater growth among age class. Another clear difference between these rivers is their distance to the ocean (167 km for the Andreafsky River and 724 km for the Kogrukluk River); thus, differing outmigration/migration distances might have contributed to these differences in growth and life history through tributary-specific adaptations.

With regards to smolt minimum size to survive to maturity, studies have shown lower survival toward the end of outmigration in salmon smolts (Skalski 1998). This mortality could be magnified when total distance of outmigration is particularly large. If this mortality is size selective, increased migration distance in the Kogrukluk River could explain more evidence of a smolt minimum size to survive to maturity in the Kogrukluk River than in the Andreafsky River.

With regards to maturing early (1.2 age fish), longer return migration distances may select for larger and therefore older fish that have more energy reserves (Jonsson et al. 1997). Increased time in the marine environment exposes individuals to predators, increasing the chance of mortality (Quinn et al. 2001). In the absence of selection for large size (and age) due to migration distance, a higher proportion of early maturing individuals might be expected in rivers with shorter migration distances. Length of migration distance to spawning grounds could possibly explain higher occurrence of maturing early in the Andreafsky River than in the Kogrukluk River, although sex misidentification might have also contributed to this result (discussed in following paragraph).

Finally, I observed no significant variation in freshwater growth among age classes in the Kogrukluk River, whereas in the Andreafsky River 1.2 females showed less freshwater growth than did 1.3 and 1.4 females. Relaxed selection on freshwater growth due to a shorter migration distance could have allowed for greater variation in freshwater growth among age classes in the Andreafsky River. However, a more likely explanation could be sex misidentification in the Andreafsky River. Chinook salmon identified as 1.2 age females in the Andreafsky River may in fact be mostly males that were sexed incorrectly in the field due to shortcomings of visual sex identification, which is thought to be less of a concern in the Kogrukluk River (L. DuBois, ADF&G, personal communication, 2011). Male Chinook salmon are known to have more life-history strategies than female Chinook salmon, with one tactic being maturing early and “sneaking” to fertilize eggs (Zabel et al. 2006). If males grow more slowly in freshwater (as has been observed in Atlantic salmon *Salmo salar;* Morgan and Metcalfe 2001), then differences between 1.2

and the other age classes could result from erroneously identifying these 1.2 individuals as female. If in fact most 1.2 age females in the Andreafsky River are 1.2 age males, it could explain the higher occurrence of maturing early in the Andreafsky River (n=165) than in the Kogrukluk River (n=16) seen in this study.

## 5 Conclusions

Chinook salmon are important in the Y-K region of Alaska and have supported those who live in this region for thousands of years. Returns have been unpredictable over the last century, with record lows in the last 15 years. People invested in the Y-K region, for both cultural and economic reasons, are concerned and want to better understand Chinook salmon to better manage the species in this region. In this study, I did not find a direct relationship between freshwater growth and recruitment in either of two tributaries of the Y-K region, suggesting that managers may need to focus on the marine environment in the future, especially considering predicted temperature increases in the marine environment that could result in restricted overall area of marine environment that would support growth (Welch et al. 1998). However, I observed declines in freshwater growth that suggest future work investigating these declines might be important for understanding the future of Chinook salmon in the Y-K region. The importance of Chinook salmon for people of the Y-K region cannot be overstated, and their management, made more effective through research, will help ensure their existence in perpetuity.

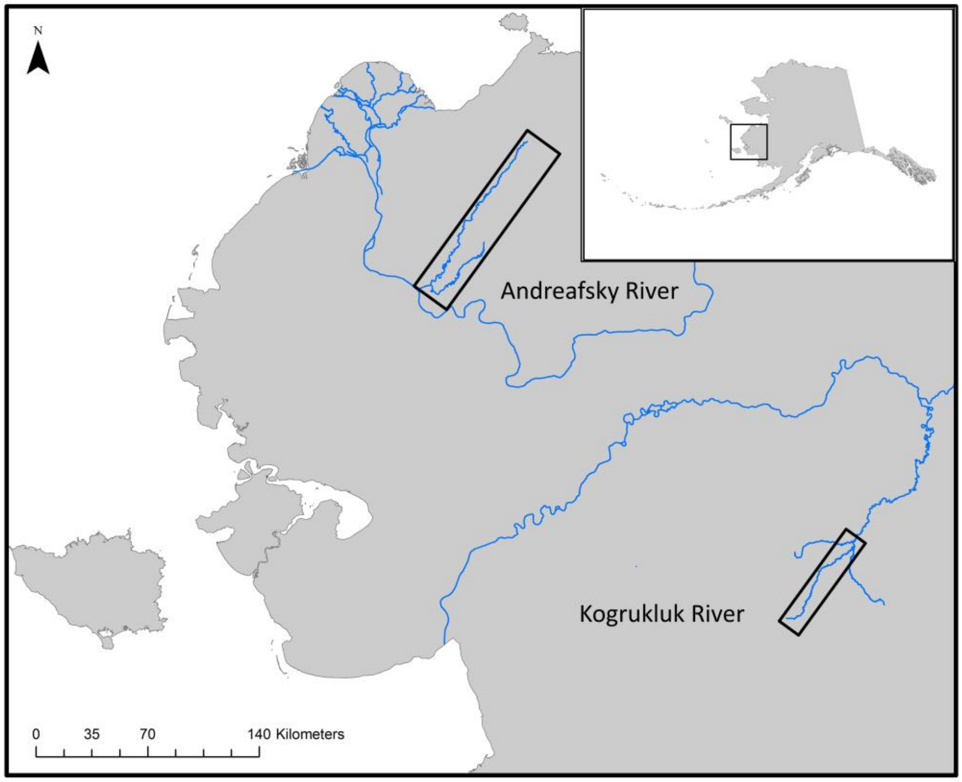


Figure 1. Study sites where scale archives originated. Boxes indicate each corresponding study site.

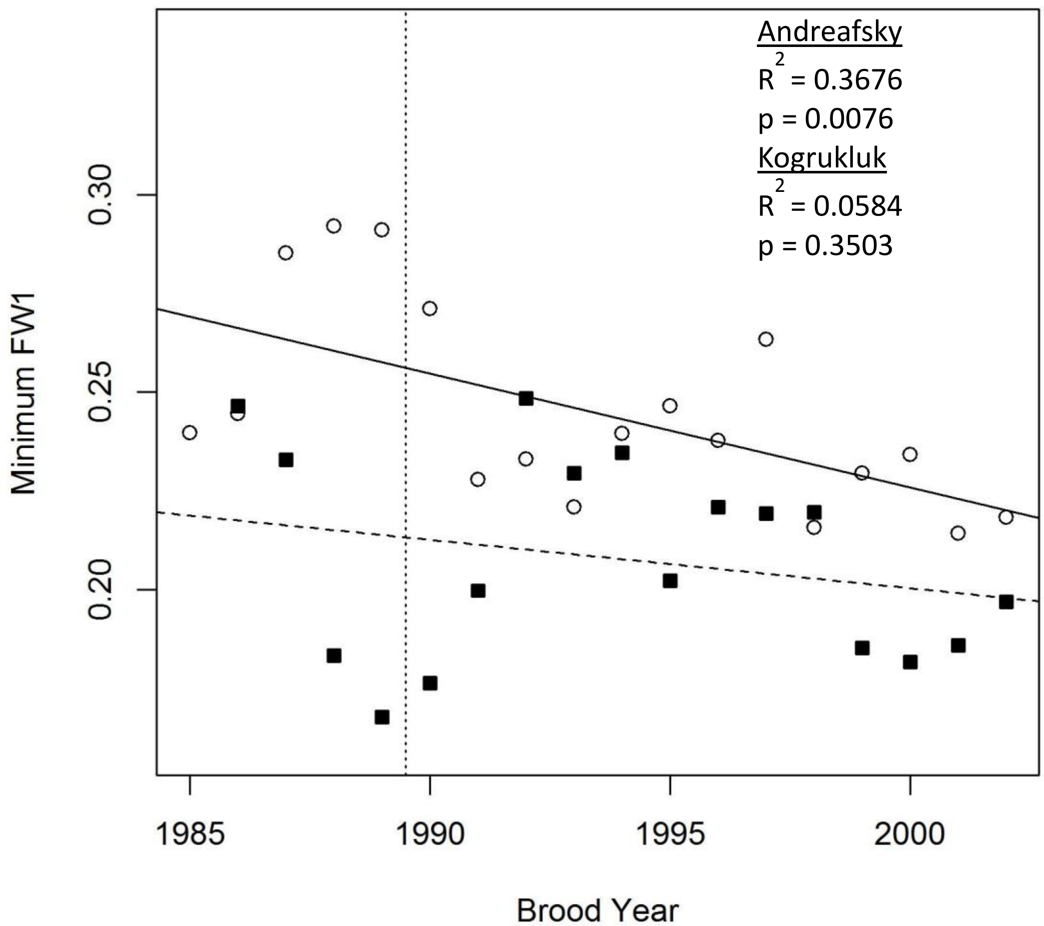


Figure 2. Minimum FW1 by brood year for both tributaries. Circles represent the Andreafsky River and squares represent the Kogrukluk River. Solid regression line represents the Andreafsky River and dashed regression line represents the Kogrukluk River. Vertical dotted line represents point at which brood years began contributing to late 1990s stock returns.

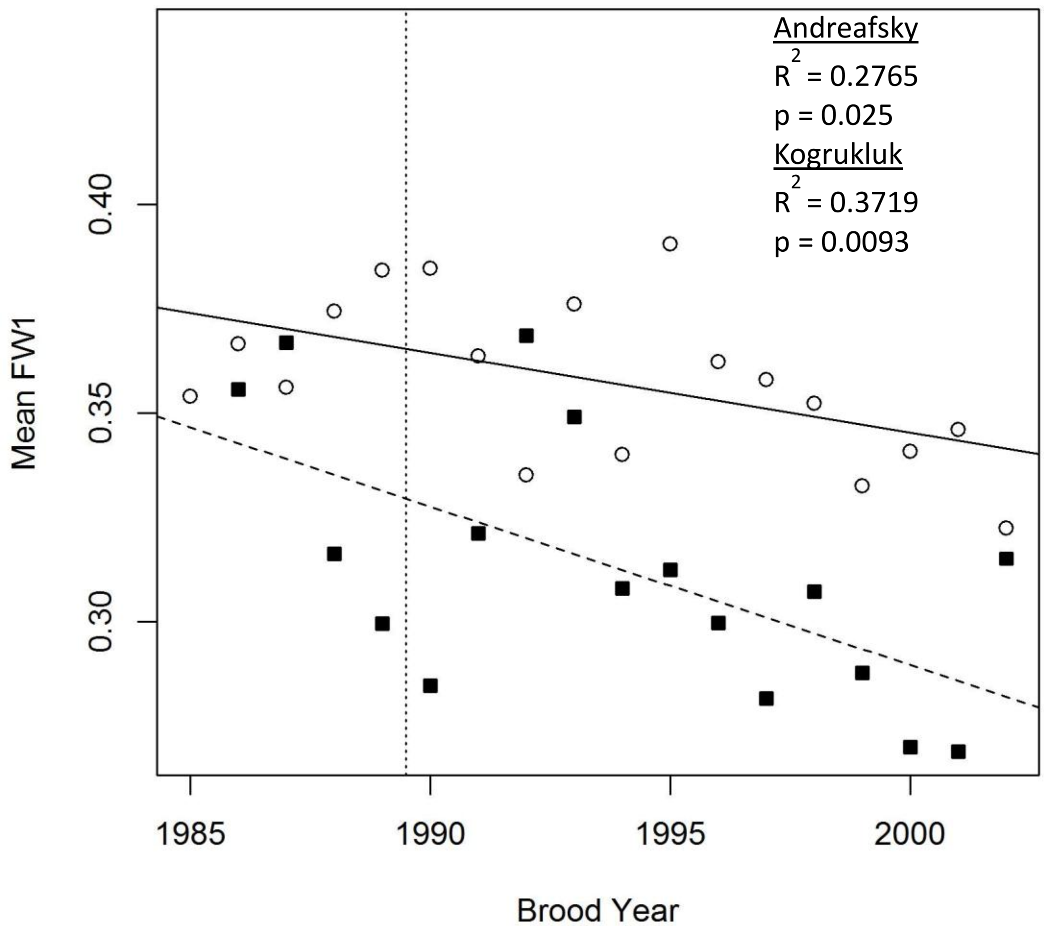


Figure 3. Mean FW1 by brood year for both tributaries. Circles represent the Andreafsky River and squares represent the Kogrukluk River. Solid regression line represents the Andreafsky River and dashed regression line represents the Kogrukluk River. Vertical dotted line represents the point at which brood years began contributing to late 1990s stock returns.

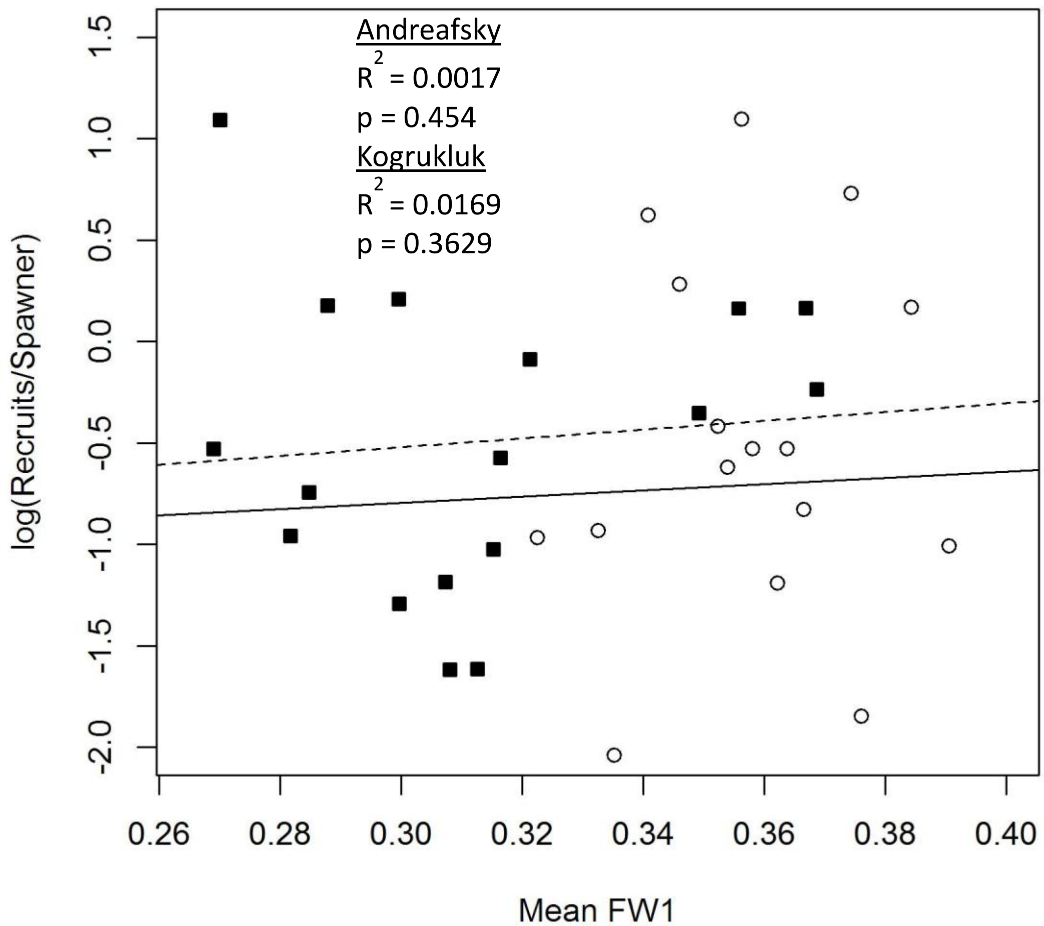


Figure 4. Log(recruits/spawner) versus mean FW1 per brood year for both tributaries. Circles represent the Andreafsky River and squares represent the Kogrukluk River. The Andreafsky River regression line is solid and the Kogrukluk River regression line is dashed.

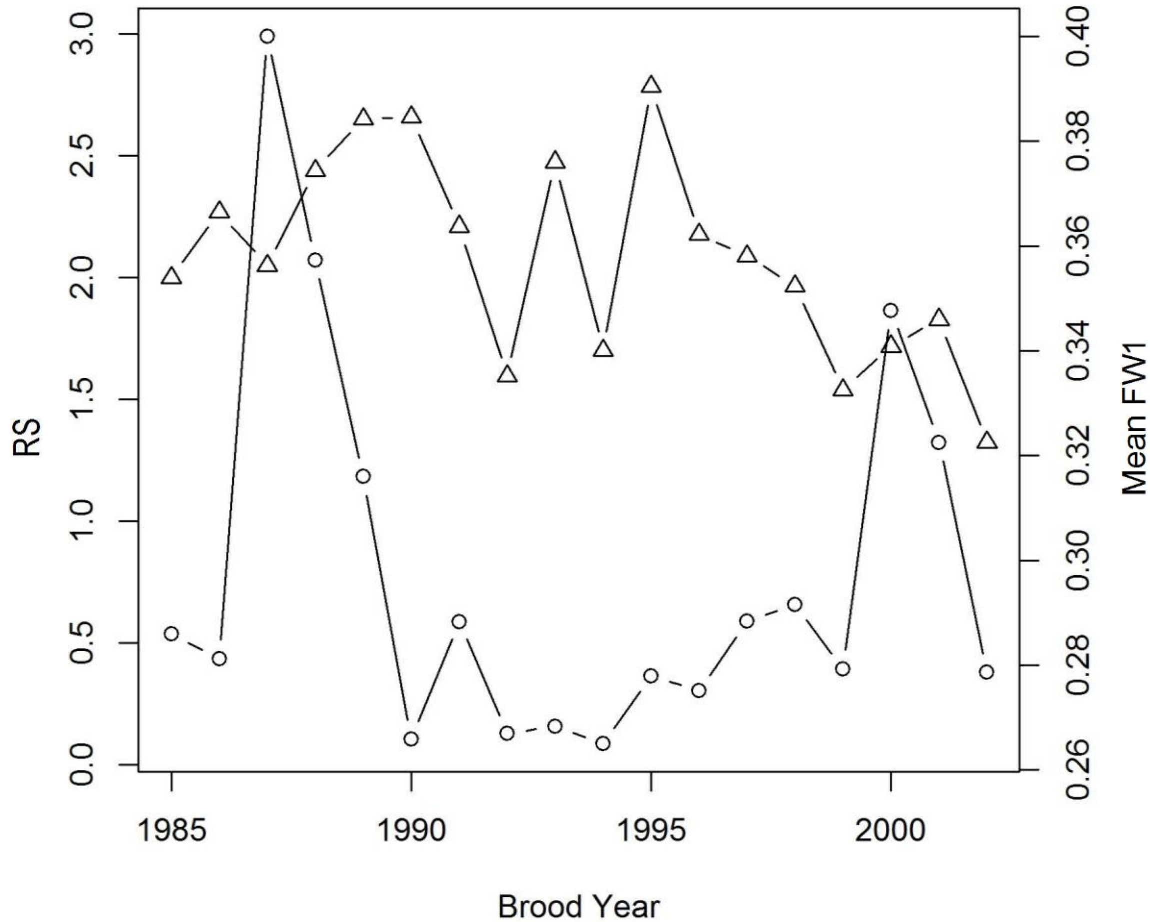


Figure 5. Andreafsky River recruits/spawner (circles) and mean FW1 (triangles) versus brood year.

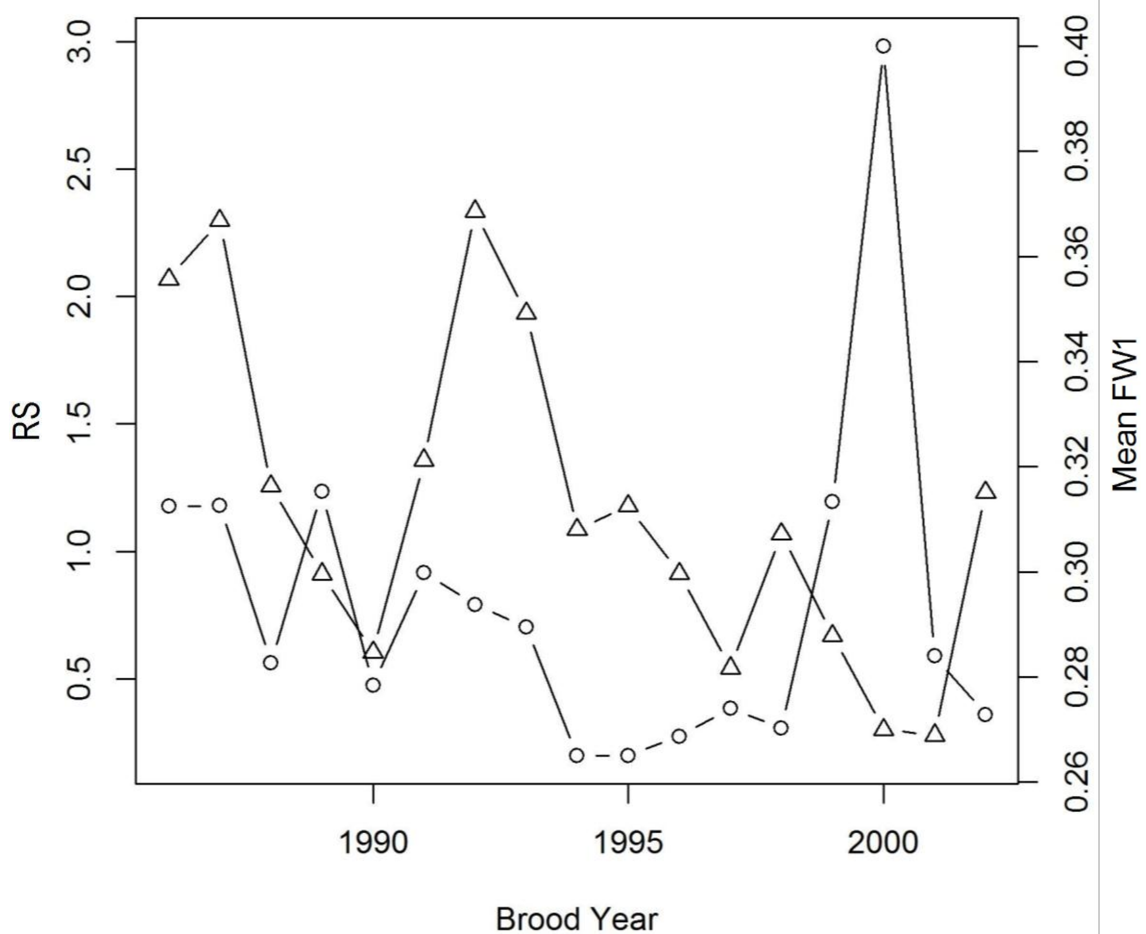


Figure 6. Kogrukluk River recruits/spawner (circles) and mean FW1 (triangles) versus brood year.

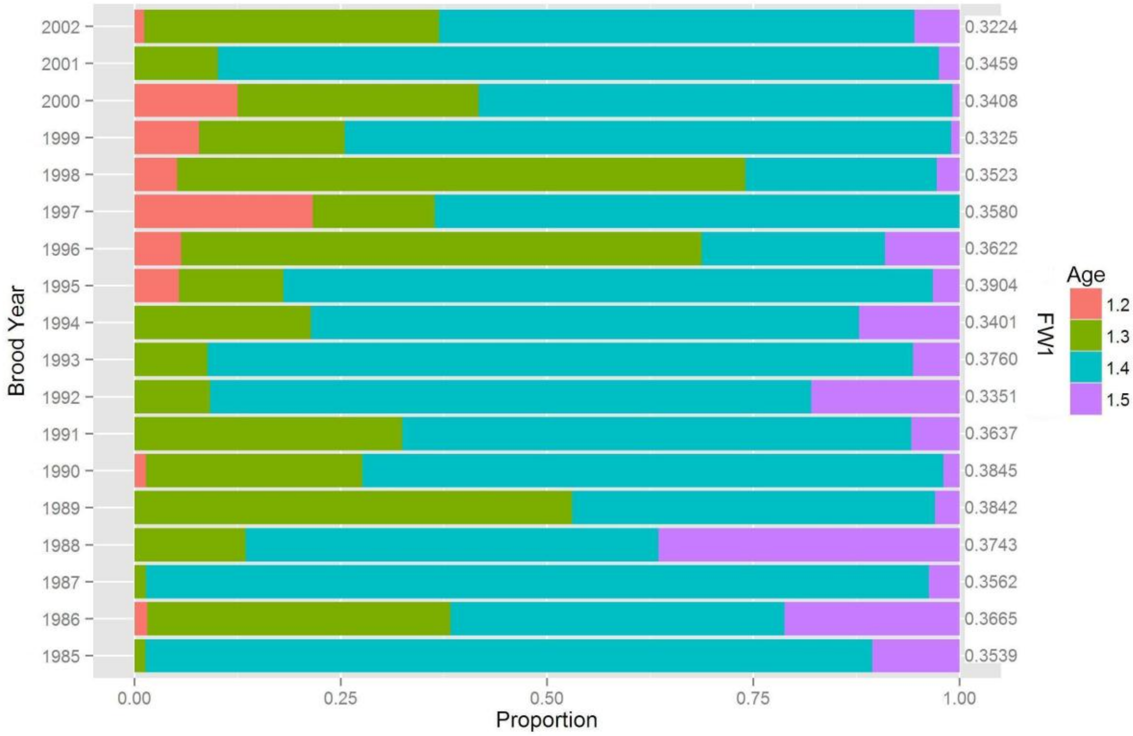


Figure 7. Stacked bar plot displaying Andreafsky River age class proportions by brood year. The right axis displays the mean FW1 for the corresponding brood year on the left.

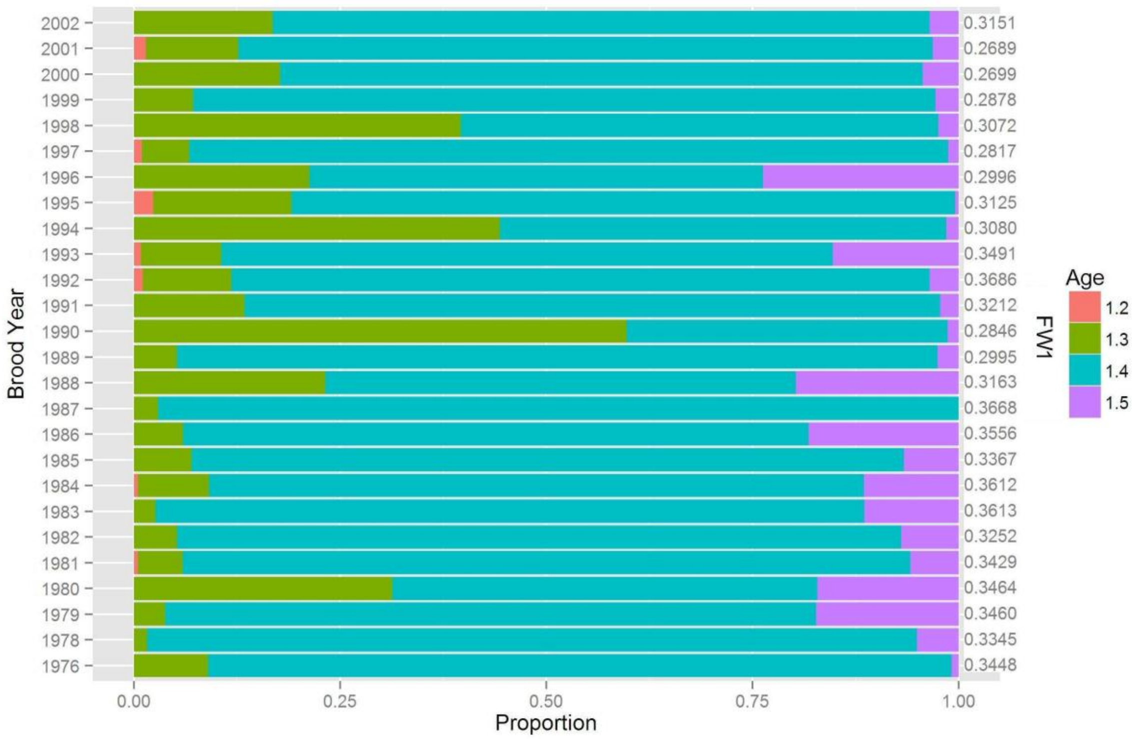


Figure 8. Stacked bar plot displaying Kogrukluk River age class proportions by brood year. The right axis displays the mean FW1 for the corresponding brood year on the left.

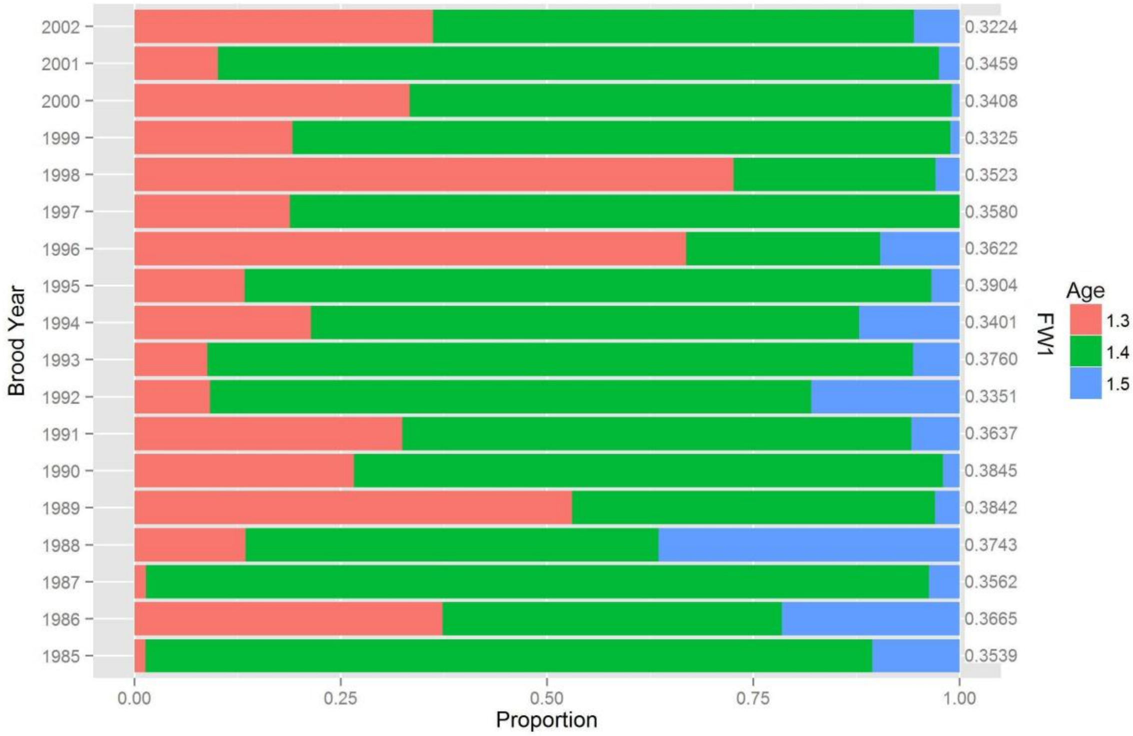


Figure 9. Stacked bar plot displaying Andreafsky River age class proportions by brood year, without 1.2 age class. The right axis displays the mean FW1 for the corresponding brood year on the left.

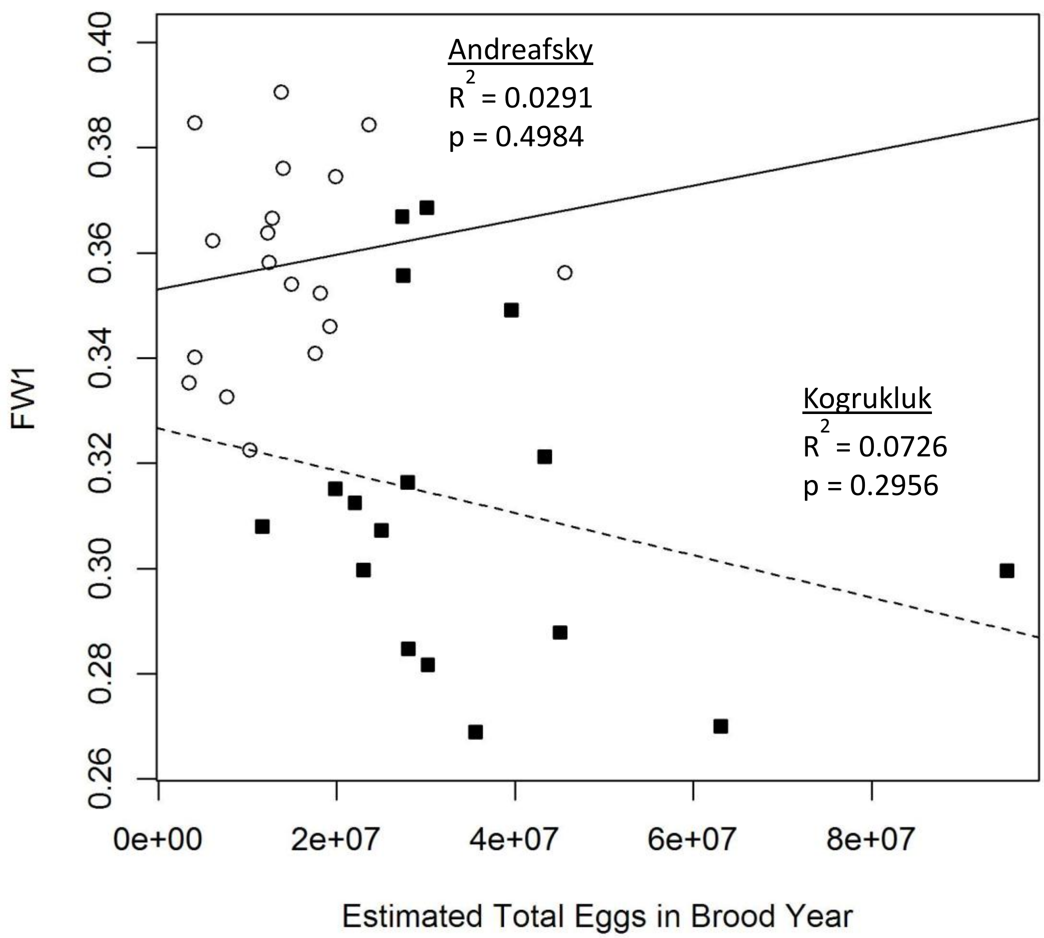


Figure 10. Mean FW1 per brood year versus estimated total eggs in brood year for both tributaries. Circles represent the Andreafsky River and squares represent the Kogrukluk River. The Andreafsky River regression line is solid and the Kogrukluk River regression line is dashed.

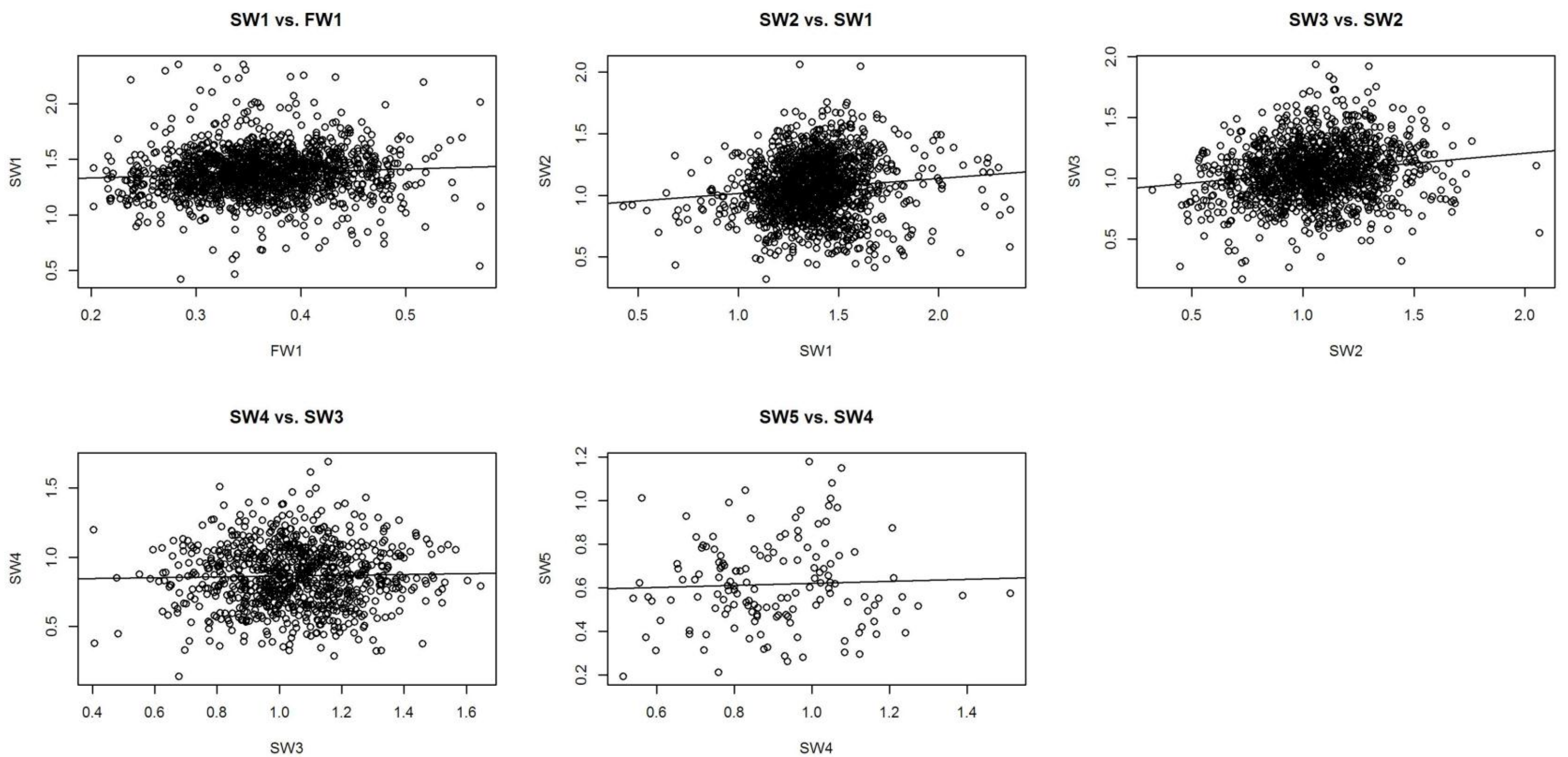


Figure 11. Andreafsky River zones of growth in relation to the growth of the previous zone.

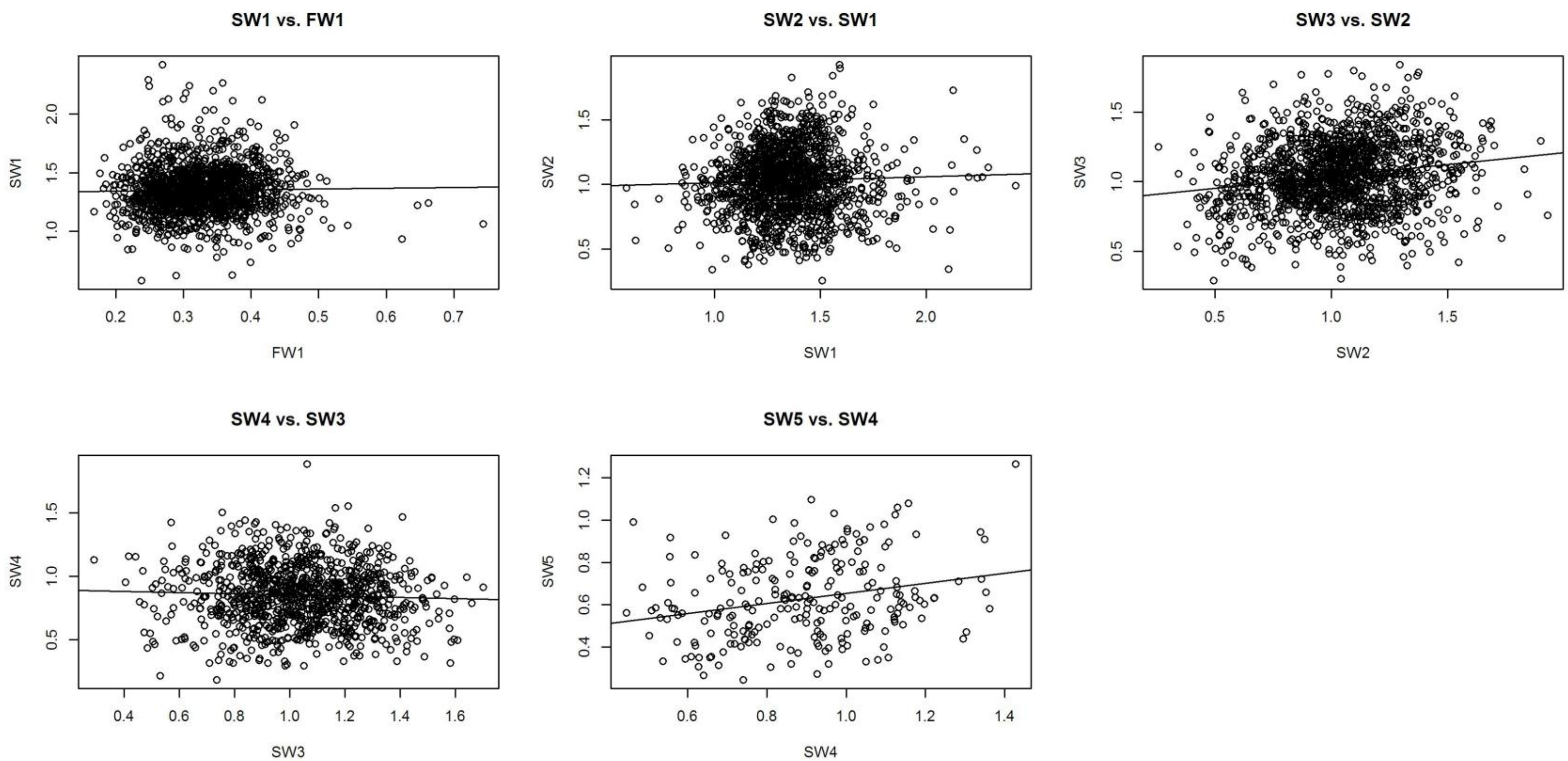


Figure 12. Kogrukluk River zones of growth in relation to the growth of the previous zone.

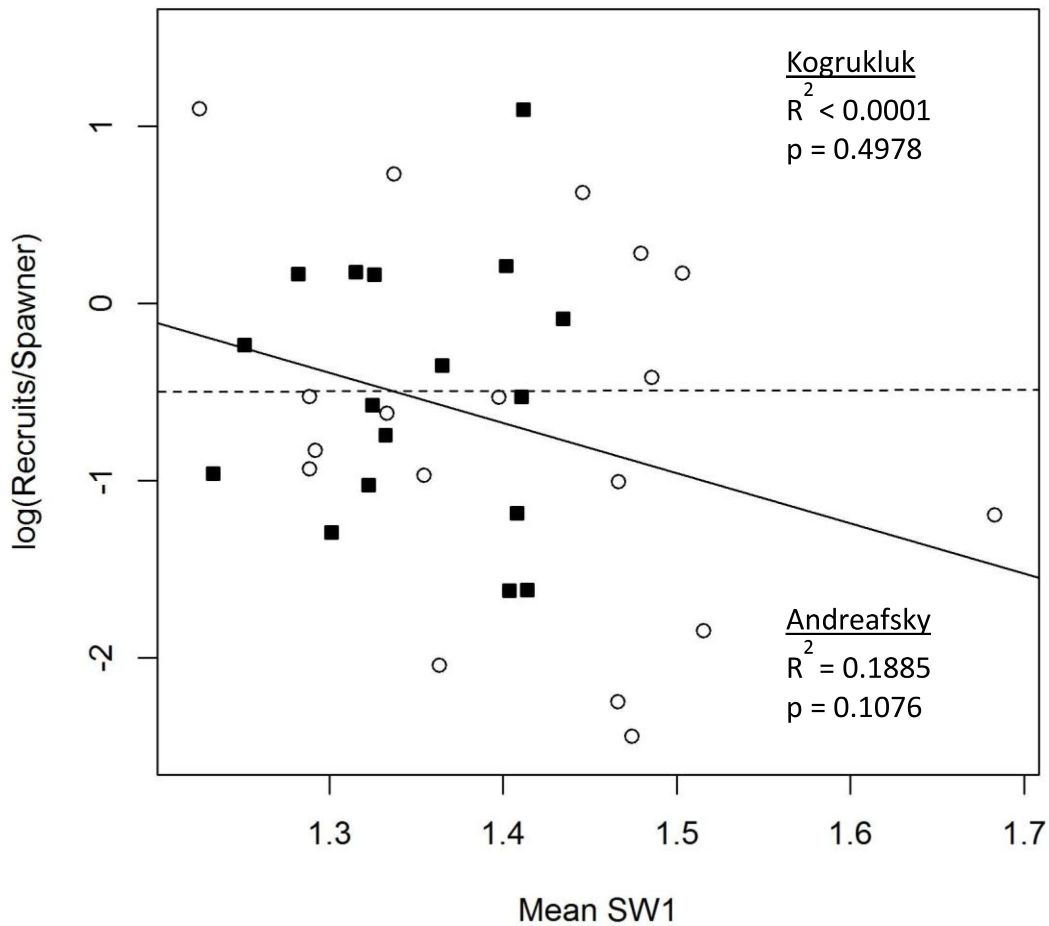


Figure 13. Log(recruits/spawner) versus mean SW1 per brood year for both tributaries. Circles represent the Andreafsky River and squares represent the Kogrukluk River. The Andreafsky River regression line is solid and the Kogrukluk River regression line is dashed.

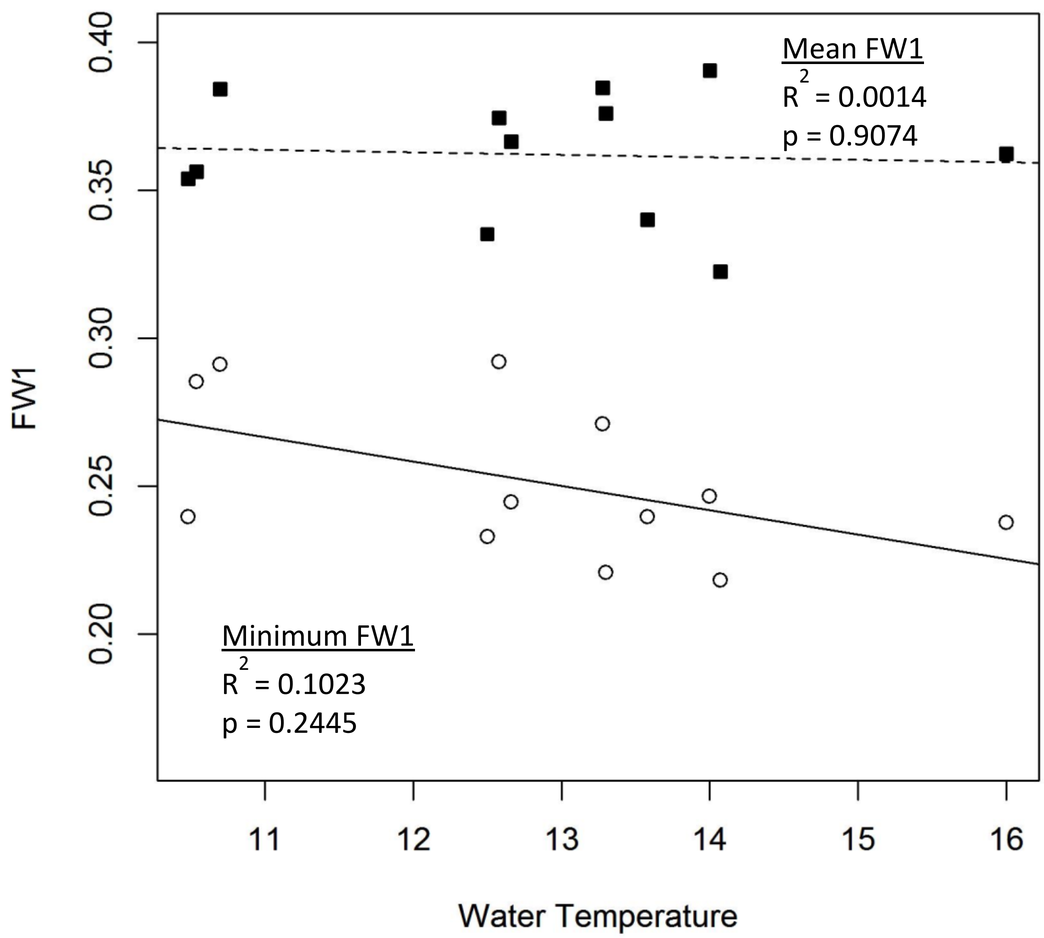


Figure 14. Andreafsky River minimum FW1 and mean FW1 per brood year versus water temperature (°C). Minimum FW1 is represented by circles and the solid regression line and mean FW1 is represented by squares and the dashed regression line.

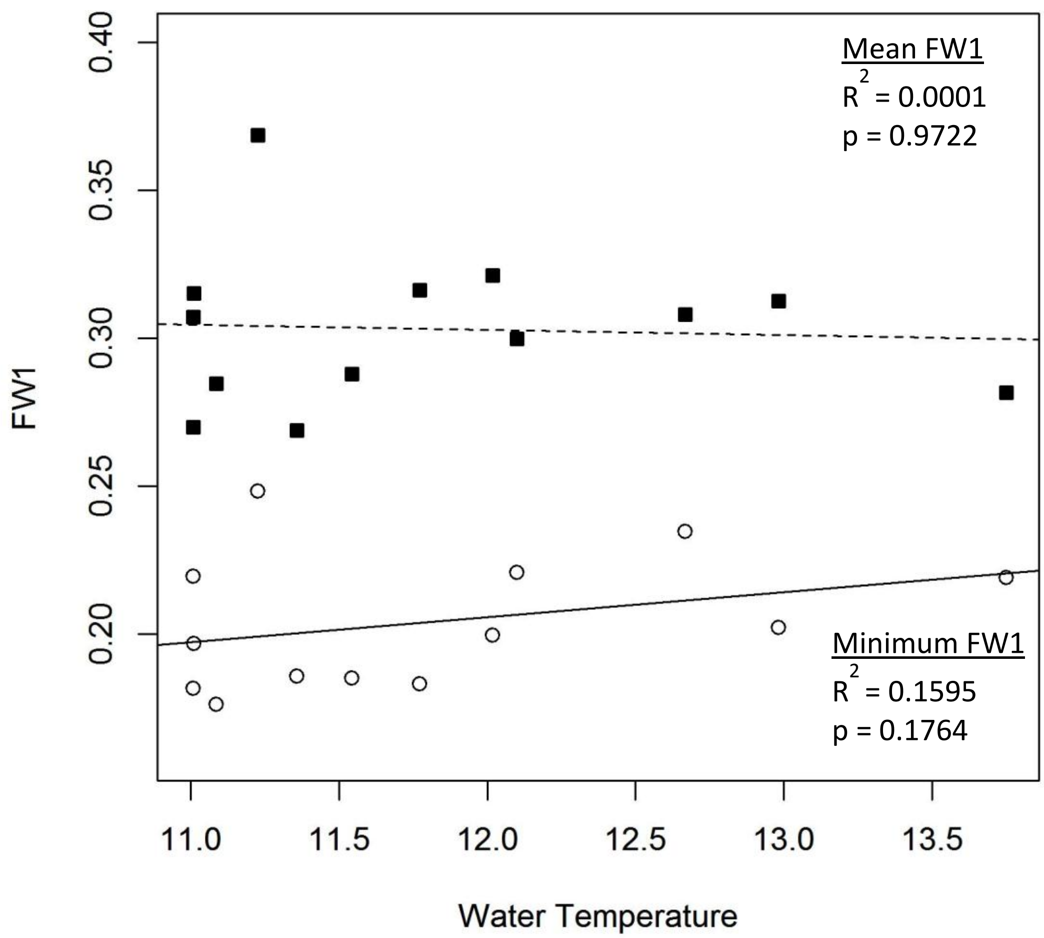


Figure 15. Kogrukluk River minimum FW1 and mean FW1 per brood year versus water temperature (°C). Minimum FW1 is represented by circles and the solid regression line and mean FW1 is represented by squares and the dashed regression line.

Table 1. Andreafsky River Chinook salmon brood table.

| Year of Arrival | Estimated Total Escapement | Female Brood Year Recruits Age | | | | | | Female Brood Return | Recruits per Spawner |
|---|---|---|---|---|---|---|---|---|---|
| | | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | | |
| 1985 | 3,956[a] | 0 | 0 | 737 | 1,209 | 179 | 0 | 2,125 | 0.54 |
| 1986 | 4,916[b] | 0 | 37 | 687 | 1,122 | 281 | 18 | 2,145 | 0.44 |
| 1987 | 2,011[a] | 0 | 0 | 104 | 5,565 | 344 | 0 | 6,012 | 2.99 |
| 1988 | 1,339[a] | 0 | 0 | 419 | 2,267 | 88 | 0 | 2,774 | 2.07 |
| 1989 | 3,335[b] | 0 | 0 | 732 | 3,109 | 104 | 0 | 3,946 | 1.18 |
| 1990 | 6,480[b] | 0 | 0 | 359 | 327 | 0 | 0 | 686 | 0.11 |
| 1991 | 4,870[b] | 0 | 144 | 1,129 | 1,558 | 34 | 0 | 2,865 | 0.59 |
| 1992 | 4,542[c] | 0 | 72 | 155 | 352 | 10 | 0 | 590 | 0.13 |
| 1993 | 16,029[b] | 8 | 292 | 1,019 | 1,209 | 0 | 0 | 2,528 | 0.16 |
| 1994 | 7,801[a] | 0 | 55 | 200 | 385 | 40 | 0 | 679 | 0.09 |
| 1995 | 5,841[a] | 0 | 79 | 224 | 1,779 | 49 | 0 | 2,133 | 0.37 |
| 1996 | 2,955[a] | 0 | 59 | 179 | 608 | 51 | 0 | 897 | 0.30 |
| 1997 | 3,186[a] | 0 | 0 | 348 | 1,483 | 48 | 0 | 1,879 | 0.59 |
| 1998 | 4,034[a] | 0 | 10 | 879 | 1,750 | 12 | 0 | 2,650 | 0.66 |
| 1999 | 3,444[a] | 0 | 141 | 752 | 461 | 0 | 0 | 1,354 | 0.39 |
| 2000 | 1,609[a] | 0 | 637 | 1,011 | 1,331 | 20 | 0 | 2,999 | 1.86 |
| 2001 | 2,384[b] | 0 | 73 | 1,340 | 1,678 | 64 | 0 | 3,155 | 1.32 |
| 2002 | 4,123[a] | 0 | 163 | 543 | 841 | 13 | 3 | 1,564 | 0.38 |

Table 1 continued…

Total escapements obtained from Matthew Evenson, ADF&G Biometrician

[a]Total escapements determined by weir estimates.

[b]Total escapement determined by conversion of aerial survey estimates to weir estimates.

[c]No aerial surveys flown. Average escapement (1985-2010) used because it was above minimal escapement counts.

Harvest acquired for the following years from the following sources:

1985-1996 - Lingnau (2000)
1997 - Lingnau and Bromaghin (1999)
1998 - Lingnau (1999)
1999 - Moore and Price (2001)
2000 - Moore and Lingnau (2002)
2001 - Moore (2002)
2002 - DuBois (2004)
2003 - DuBois (2005)
2004 - DuBois et al. (2009)
2005 - DuBois and DeCovich (2008)
2006 - DuBois (2011a)
2007 - DuBois (2011b)
2008 - Leba and DuBois (2011)
2009 - Preliminary data from Larry DuBois, ADF&G Fishery Biologist III
2010 - Preliminary data from Larry DuBois, ADF&G Fishery Biologist III

Age compositions taken from Horne-Brine and DuBois (2010).

Sex compositions taken from scale samples - representative of population because samples from escapement projects. Compared with Horne-Brine and DuBois (2010) sex compositions for accuracy.

Harvest calculated as proportion of total Yukon River basin destined for Andreafsky River.

Table 2. Kogrukluk River Chinook salmon brood table.

| ***Year of Arrival*** | ***Estimated Total Escapement*** | ***Female Brood Year Recruits Age 1.2*** | ***1.3*** | ***1.4*** | ***1.5*** | ***Female Brood Return*** | ***Recruits per Spawner*** |
|---|---|---|---|---|---|---|---|
| 1986 | 5,038 | 0 | 1,071 | 3,952 | 909 | 5,932 | 1.18 |
| 1987 | 4,063[a] | 0 | 502 | 4,174 | 114 | 4,790 | 1.18 |
| 1988 | 8,520 | 50 | 549 | 4,142 | 59 | 4,800 | 0.56 |
| 1989 | 11,940[a] | 47 | 3,389 | 10,150 | 1,148 | 14,735 | 1.23 |
| 1990 | 10,214 | 0 | 2,118 | 2,659 | 78 | 4,856 | 0.48 |
| 1991 | 7,850 | 294 | 1,027 | 5,654 | 207 | 7,183 | 0.92 |
| 1992 | 6,755 | 0 | 352 | 4,826 | 162 | 5,340 | 0.79 |
| 1993 | 12,332 | 59 | 3,299 | 5,178 | 139 | 8,675 | 0.70 |
| 1994 | 15,227 | 0 | 412 | 2,476 | 128 | 3,016 | 0.20 |
| 1995 | 20,630 | 0 | 563 | 3,411 | 132 | 4,105 | 0.20 |
| 1996 | 14,199 | 0 | 457 | 2,982 | 459 | 3,897 | 0.27 |
| 1997 | 13,286 | 57 | 629 | 4,259 | 152 | 5,096 | 0.38 |
| 1998 | 12,107 | 0 | 410 | 3,159 | 136 | 3,704 | 0.31 |
| 1999 | 5,570 | 0 | 657 | 5,183 | 813 | 6,653 | 1.19 |
| 2000 | 3,310 | 152 | 4,043 | 5,285 | 391 | 9,871 | 2.98 |
| 2001 | 9,297 | 54 | 1,889 | 3,465 | 76 | 5,484 | 0.59 |
| 2002 | 10,099 | 0 | 1,191 | 2,221 | 209 | 3,621 | 0.36 |

Table 2 continued…

Total escapements taken from uncomplete brood table acquired from Chris Shelden, ADF&G Kuskokwim Fisheries Biologist

Total escapements determined by weir estimates.

[a]Total escapement estimated from ratio of known weir escapement and known aerial assessment from year immediately after.

Harvest acquired from Christopher Shelden, ADF&G Kuskokwim Fisheries Biologist

Age compositions taken from Molyneaux et al. (2010b).

Sex compositions taken from scale samples - representative of population because samples from escapement projects.

Harvest calculated as proportion of total Upper Kuskokwim River basin destined for Kogrukluk River.

Upper Kuskokwim River portion - averaged over five years (2003 -2007) - acquired from Schaberg et al. (2012).

Kogrukluk River portion - averaged over six years (2002 -2007) - acquired from Schaberg et al. (2012).

Table 3. Data transformations necessary to maintain normality assumptions.

| | Transformation | |
|---|---|---|
| Relationship | Andreafsky | Kogrukluk |
| FW1 vs R/S | log(R/S) | log(R/S) |
| Eggs vs FW1 | FW1^1/4 | (1/FW1^2) |
| SW1 vs R/S | log(R/S) | log(R/S) |
| Temp vs Minimum FW1 | (1/FW1^2) | (1/FW1^3) |
| Temp vs Mean FW1 | FW1^5 | (1/FW1^3) |

Table 4. Examination of data and check against normal distribution of FW1 for both tributaries by brood year. P-values listed are for Shapiro-Wilks test for normality. Significant p-values are bold and N represents sample sizes. Ranges listed show minimum and maximum FW1, FW1 mean shows average FW1, and FW1 SD shows standard deviation.

| Andreafsky River | | | | | | | Kogrukluk River | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brood Year | N | P | Range | Mean FW1 | FW1 SD | | Brood Year | N | P | Range | Mean FW1 | FW1 SD |
| 1974 | 6 | **0.0058** | 0.2850-0.5705 | 0.3680 | 0.1017 | | 1970 | 1 | N/A | 0.2702-0.2702 | 0.2702 | NA |
| 1975 | 42 | 0.1835 | 0.2340-0.5712 | 0.3693 | 0.0764 | | 1971 | 31 | 0.1542 | 0.2277-0.5074 | 0.3237 | 0.0621 |
| 1976 | 41 | 0.6411 | 0.2702-0.4773 | 0.3923 | 0.0477 | | 1972 | 25 | 0.9199 | 0.2859-0.5002 | 0.3776 | 0.0540 |
| 1977 | 44 | 0.5477 | 0.2869-0.5467 | 0.4263 | 0.0545 | | 1973 | 2 | N/A | 0.3185-0.4344 | 0.3765 | 0.0820 |
| 1978 | 48 | 0.2687 | 0.2501-0.4839 | 0.3716 | 0.0646 | | 1974 | 16 | 0.3326 | 0.2671-0.4498 | 0.3375 | 0.0562 |
| 1979 | 44 | 0.2521 | 0.2959-0.5027 | 0.3949 | 0.0548 | | 1975 | 40 | 0.526 | 0.2127-0.4761 | 0.3531 | 0.0601 |
| 1980 | 31 | 0.6919 | 0.2337-0.4791 | 0.3624 | 0.0480 | | 1976 | 48 | 0.5078 | 0.2433-0.4607 | 0.3495 | 0.0573 |
| 1981 | 72 | 0.1549 | 0.2190-0.4978 | 0.3735 | 0.0635 | | 1977 | 53 | 0.203 | 0.2482-0.4564 | 0.3557 | 0.0514 |
| 1982 | 27 | 0.5526 | 0.2469-0.4746 | 0.3670 | 0.0647 | | 1978 | 38 | **0.0046** | 0.2324-0.5189 | 0.3331 | 0.0606 |
| 1983 | 26 | 0.2542 | 0.2765-0.4804 | 0.3551 | 0.0569 | | 1979 | 49 | **9.63E-06** | 0.2518-0.6627 | 0.3578 | 0.0699 |
| 1984 | 47 | 0.6213 | 0.2590-0.5168 | 0.3635 | 0.0523 | | 1980 | 36 | 0.9542 | 0.2518-0.4606 | 0.3481 | 0.0486 |
| 1985 | 49 | 0.7256 | 0.2397-0.4955 | 0.3699 | 0.0625 | | 1981 | 55 | 0.302 | 0.2295-0.4351 | 0.3215 | 0.0486 |
| 1986 | 36 | 0.9436 | 0.2446-0.4699 | 0.3650 | 0.0504 | | 1982 | 28 | **1.19E-05** | 0.2518-0.6232 | 0.3250 | 0.0717 |
| 1987 | 42 | 0.0871 | 0.2853-0.5088 | 0.3676 | 0.0523 | | 1983 | 51 | 0.9255 | 0.2306-0.4666 | 0.3471 | 0.0508 |
| 1988 | 40 | 0.1065 | 0.2921-0.5147 | 0.3736 | 0.0451 | | 1984 | 33 | 0.7515 | 0.2294-0.4743 | 0.3620 | 0.0538 |
| 1989 | 61 | 0.1797 | 0.2911-0.5312 | 0.3807 | 0.0470 | | 1985 | 55 | 0.3312 | 0.2380-0.4800 | 0.3435 | 0.0558 |
| 1990 | 34 | 0.0736 | 0.2711-0.5709 | 0.3856 | 0.0594 | | 1986 | 56 | 0.6304 | 0.2465-0.4522 | 0.3541 | 0.0509 |
| 1991 | 62 | 0.4746 | 0.2278-0.4831 | 0.3727 | 0.0567 | | 1987 | 38 | 0.6611 | 0.2329-0.4726 | 0.3585 | 0.0612 |
| 1992 | 47 | 0.7169 | 0.2330-0.4926 | 0.3450 | 0.0604 | | 1988 | 36 | 0.9531 | 0.1832-0.5086 | 0.3325 | 0.0665 |

Table 4 continued…

Andreafsky River

| Brood Year | N | P | Range | Mean FW1 | FW1 SD |
|---|---|---|---|---|---|
| 1993 | 76 | 0.4812 | 0.2209-0.5424 | 0.4052 | 0.0639 |
| 1994 | 46 | 0.4702 | 0.2396-0.4858 | 0.3468 | 0.0529 |
| 1995 | 62 | 0.7032 | 0.2465-0.4766 | 0.3823 | 0.0485 |
| 1996 | 47 | **0.0006** | 0.2378-0.5536 | 0.3377 | 0.0544 |
| 1997 | 53 | 0.0539 | 0.2634-0.4244 | 0.3555 | 0.0383 |
| 1998 | 53 | 0.8036 | 0.2157-0.4821 | 0.3408 | 0.0580 |
| 1999 | 56 | 0.7688 | 0.2294-0.4573 | 0.3268 | 0.0502 |
| 2000 | 50 | 0.4656 | 0.2341-0.4350 | 0.3454 | 0.0410 |
| 2001 | 42 | 0.9075 | 0.2142-0.4463 | 0.3391 | 0.0479 |
| 2002 | 40 | 0.2239 | 0.2182-0.4136 | 0.3217 | 0.0530 |
| 2003 | 76 | 0.156 | 0.2023-0.4653 | 0.3130 | 0.0581 |
| 2004 | 37 | 0.8319 | 0.2021-0.4675 | 0.3365 | 0.0575 |
| 2005 | 29 | 0.5806 | 0.2416-0.4107 | 0.3350 | 0.0443 |
| 2006 | 25 | 0.2706 | 0.226-0.374 | 0.3025 | 0.0404 |

Kogrukluk River

| Brood Year | N | P | Range | Mean FW1 | FW1 SD |
|---|---|---|---|---|---|
| 1989 | 72 | 0.1633 | 0.1677-0.4829 | 0.3037 | 0.0682 |
| 1990 | 52 | 0.0707 | 0.1763-0.4699 | 0.2921 | 0.0609 |
| 1991 | 53 | 0.7498 | 0.1997-0.4515 | 0.3115 | 0.0501 |
| 1992 | 30 | 0.8376 | 0.2484-0.5118 | 0.3573 | 0.0624 |
| 1993 | 41 | **2.20E-05** | 0.2295-0.7433 | 0.3664 | 0.0962 |
| 1994 | 38 | 0.2601 | 0.2347-0.4330 | 0.3101 | 0.0501 |
| 1995 | 36 | 0.0722 | 0.2022-0.5016 | 0.3187 | 0.0594 |
| 1996 | 46 | 0.0965 | 0.2208-0.4111 | 0.2996 | 0.0523 |
| 1997 | 46 | **0.016** | 0.2192-0.4437 | 0.3015 | 0.0566 |
| 1998 | 40 | 0.1443 | 0.2195-0.4136 | 0.3027 | 0.0492 |
| 1999 | 58 | 0.0862 | 0.1851-0.4855 | 0.2904 | 0.0565 |
| 2000 | 60 | 0.2796 | 0.1816-0.4133 | 0.2855 | 0.0535 |
| 2001 | 54 | 0.0516 | 0.1858-0.4282 | 0.2725 | 0.0463 |
| 2002 | 48 | 0.7176 | 0.1969-0.4505 | 0.3065 | 0.0546 |
| 2003 | 51 | 0.3378 | 0.2142-0.4853 | 0.3261 | 0.0588 |
| 2004 | 46 | 0.353 | 0.2381-0.4471 | 0.3418 | 0.0537 |
| 2005 | 18 | 0.2392 | 0.2483-0.3975 | 0.3358 | 0.0478 |

Table 5. Results of Tukey multiple comparison tests for differences in FW1 between age classes for both tributaries. Significant results are shown in bold.

| | Tributary | |
|---|---|---|
| | Andreafsky River | Kogrukluk River |
| Age Classes | P | P |
| 1.3-1.2 | **0.0169** | 0.9999 |
| 1.4-1.2 | **0.0168** | 0.9994 |
| 1.5-1.2 | 0.0992 | 0.9858 |
| 1.4-1.3 | 0.997 | 0.9898 |
| 1.5-1.3 | 0.9999 | 0.6043 |
| 1.5-1.4 | 0.9999 | 0.3851 |
| Overall | 0.019 | 0.466 |

Table 6. Correlations between growth zones for Andreafsky and Kogrukluk rivers. Correlations shown are Pearson's correlations. Significant results are shown in bold.

Andreafsky River

| | SW1-FW1 | SW2-SW1 | SW3-SW2 | SW4-SW3 | SW5-SW4 |
|---|---|---|---|---|---|
| Correlation | 0.0747 | 0.1115 | 0.1659 | 0.0251 | 0.0425 |
| p | **0.0039** | **1.60E-06** | **1.27E-09** | 0.4636 | 0.6117 |

Kogrukluk River

| | SW1-FW1 | SW2-SW1 | SW3-SW2 | SW4-SW3 | SW5-SW4 |
|---|---|---|---|---|---|
| Correlation | 0.0189 | 0.0372 | 0.1772 | -0.0458 | 0.2495 |
| p | 0.4684 | 0.1523 | **8.80E-12** | 0.1423 | **0.0001** |

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**Appendix I: Scale Sample Sizes**

Table A1-1. Andreafsky River Chinook salmon scale sample sizes by year of collection and age.

Andreafsky River

| | Year of Return | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Age | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 |
| 1.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.2 | 0 | 0 | 9 | 0 | 0 | 0 | 1 | 0 |
| 1.3 | 8 | 14 | 8 | 2 | 8 | 2 | 23 | 1 |
| 1.4 | 5 | 30 | 27 | 30 | 27 | 25 | 24 | 25 |
| 1.5 | 0 | 1 | 4 | 0 | 6 | 10 | 11 | 5 |
| 2.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 13 | 45 | 48 | 32 | 41 | 37 | 59 | 31 |

Andreafsky River

| | Year of Return | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Age | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
| 1.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| 1.3 | 8 | 16 | 22 | 25 | 1 | 10 | 25 | 9 |
| 1.4 | 25 | 11 | 25 | 25 | 7 | 25 | 25 | 25 |
| 1.5 | 24 | 0 | 7 | 6 | 2 | 4 | 16 | 5 |
| 2.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 57 | 27 | 54 | 56 | 10 | 39 | 66 | 47 |

Table A1-1 continued…

Andreafsky River

| | Year of Return | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Age | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
| 1.1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.2 | 8 | 25 | 3 | 7 | 9 | 0 | 1 | 6 |
| 1.3 | 26 | 13 | 25 | 16 | 25 | 7 | 25 | 25 |
| 1.4 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| 1.5 | 11 | 0 | 3 | 1 | 0 | 2 | 5 | 6 |
| 2.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 71 | 63 | 56 | 49 | 59 | 34 | 56 | 62 |

Andreafsky River

| | Year of Return | | | | | |
|---|---|---|---|---|---|---|
| Age | 2004 | 2005 | 2007 | 2008 | 2009 | 2010 |
| 1.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1.2 | 24 | 10 | 25 | 2 | 2 | 25 |
| 1.3 | 25 | 25 | 13 | 25 | 8 | 25 |
| 1.4 | 25 | 25 | 25 | 24 | 25 | 25 |
| 1.5 | 3 | 2 | 1 | 7 | 1 | 1 |
| 2.2 | 0 | 0 | 0 | 0 | 0 | 2 |
| 2.3 | 0 | 0 | 0 | 1 | 0 | 2 |
| 2.5 | 0 | 0 | 0 | 0 | 0 | 1 |
| Total | 77 | 62 | 64 | 59 | 36 | 81 |

Table A1-2. Kogrukluk River Chinook salmon scale sample sizes by year of collection and age.

Kogrukluk River

| | Year of Return | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Age | 1978 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 |
| 1.2 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 1.3 | 2 | 15 | 5 | 1 | 13 | 10 | 5 | 1 |
| 1.4 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| 1.5 | 6 | 16 | 15 | 8 | 22 | 12 | 11 | 0 |
| 2.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.4 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 59 | 57 | 45 | 34 | 61 | 47 | 41 | 26 |

Kogrukluk River

| | Year of Return | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Age | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
| 1.2 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| 1.3 | 25 | 3 | 25 | 21 | 11 | 8 | 21 | 24 |
| 1.4 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| 1.5 | 25 | 2 | 1 | 5 | 4 | 9 | 2 | 2 |
| 2.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.4 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 75 | 30 | 51 | 51 | 42 | 44 | 48 | 53 |

*2.4 age class in 1978 highlighted because large number of uncommon age class

Table A1-2 continued…

Kogrukluk River

| | Year of Return | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Age | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
| 1.2 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 1.3 | 25 | 6 | 14 | 10 | 7 | 10 | 16 | 11 |
| 1.4 | 25 | 25 | 19 | 25 | 25 | 25 | 25 | 25 |
| 1.5 | 25 | 3 | 1 | 5 | 1 | 3 | 4 | 11 |
| 2.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 75 | 35 | 34 | 40 | 33 | 39 | 45 | 47 |

Kogrukluk River

| | Year of Return | | | | | | |
|---|---|---|---|---|---|---|---|
| Age | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
| 1.2 | 3 | 2 | 0 | 0 | 1 | 2 | 0 |
| 1.3 | 17 | 25 | 25 | 19 | 23 | 20 | 16 |
| 1.4 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| 1.5 | 4 | 4 | 16 | 7 | 2 | 3 | 3 |
| 2.3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 49 | 56 | 66 | 51 | 52 | 50 | 44 |

**Appendix II: Q-Q Plots**

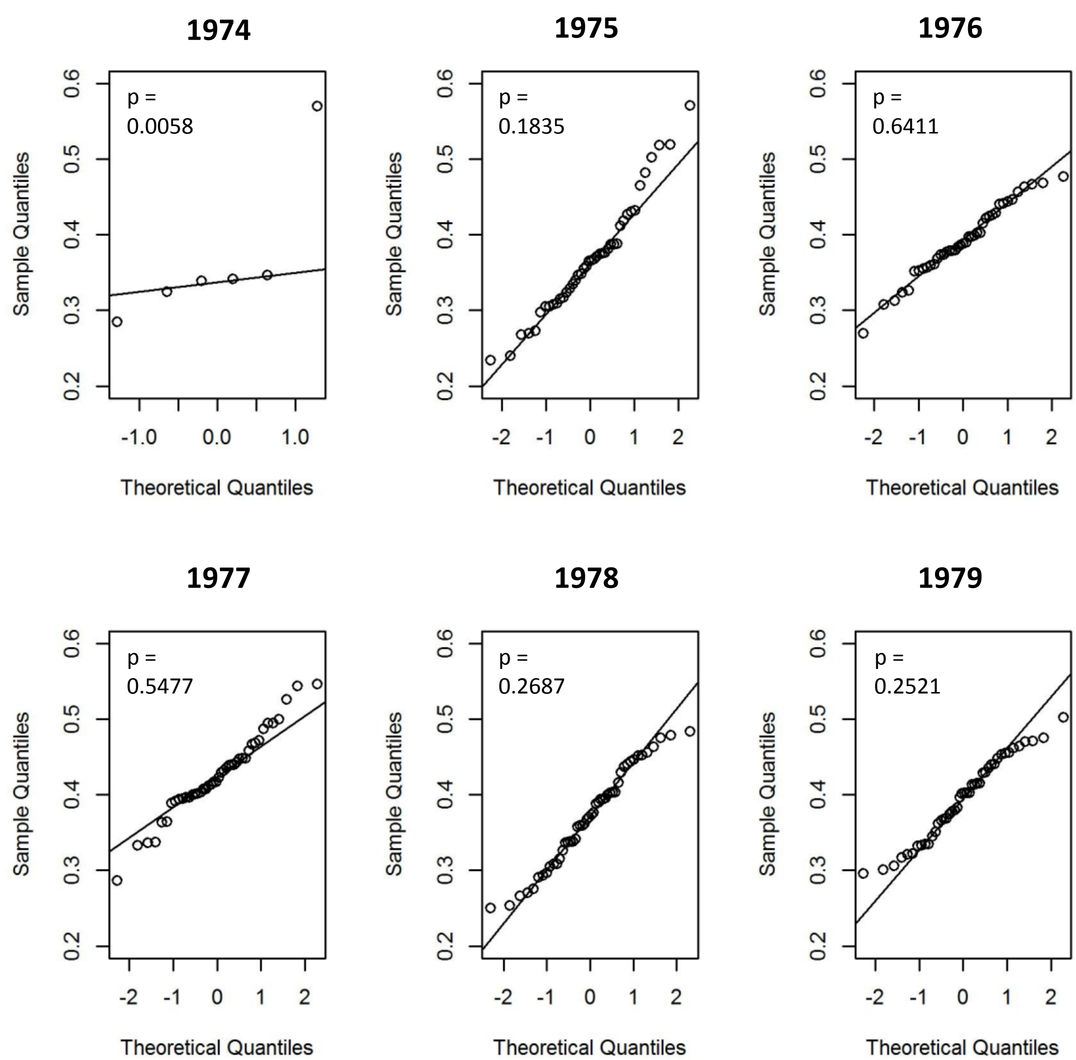


Figure A2-1. Examination of data and check against normal distribution of FW1 for Andreafsky River brood years 1974-1979. P-values listed are for Shapiro-Wilks test for normality.

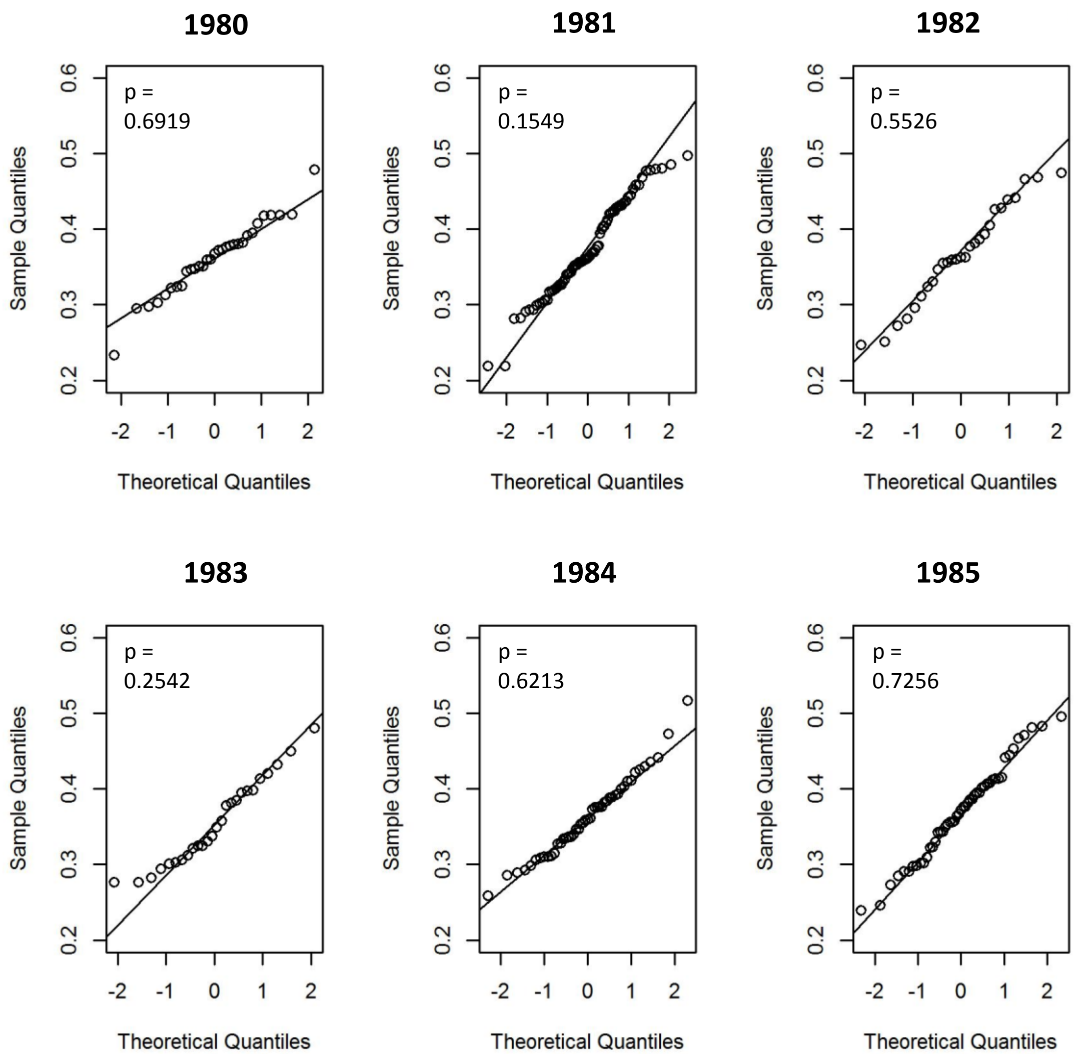


Figure A2-2. Examination of data and check against normal distribution of FW1 for Andreafsky River brood years 1980-1985. P-values listed are for Shapiro-Wilks test for normality.

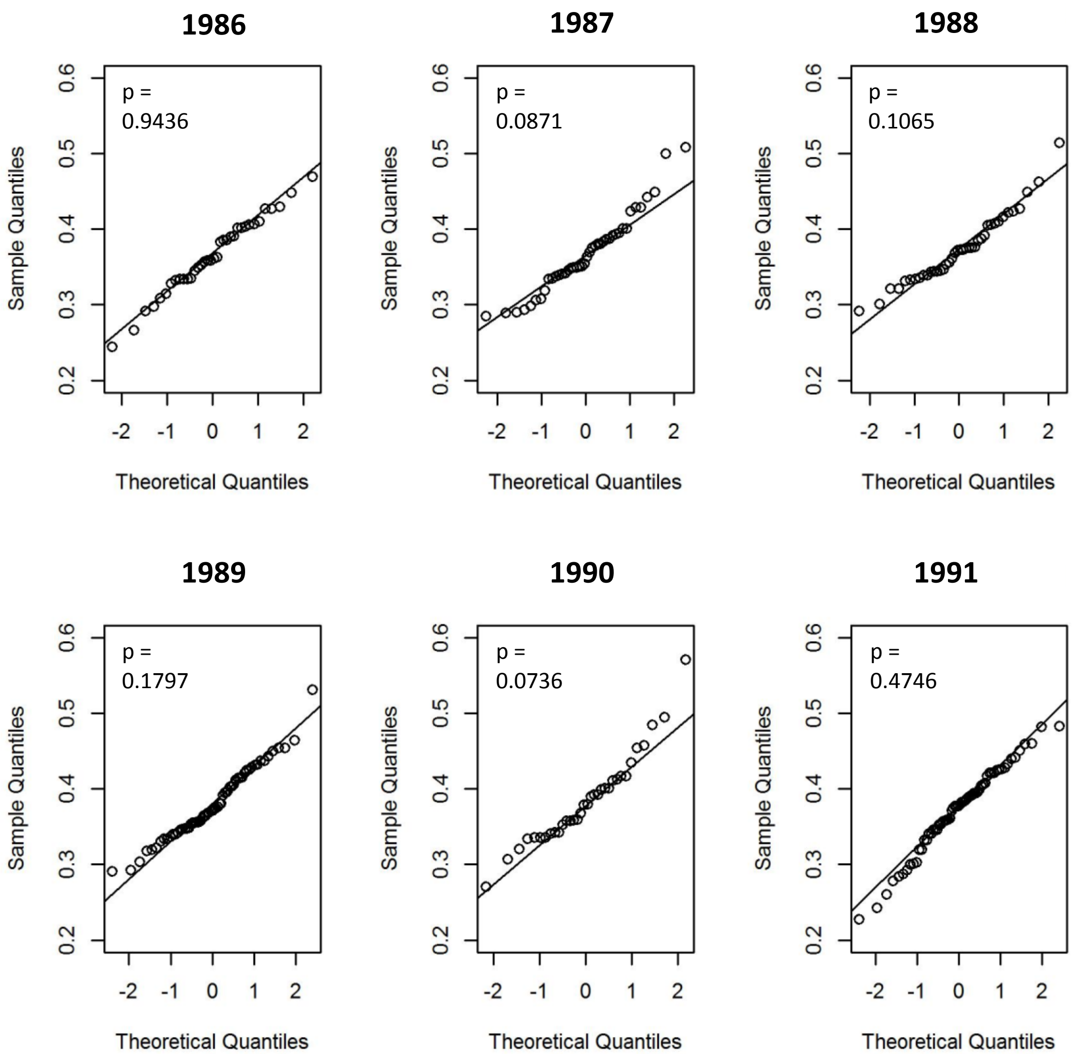


Figure A2-3. Examination of data and check against normal distribution of FW1 for Andreafsky River brood years 1986-1991. P-values listed are for Shapiro-Wilks test for normality.

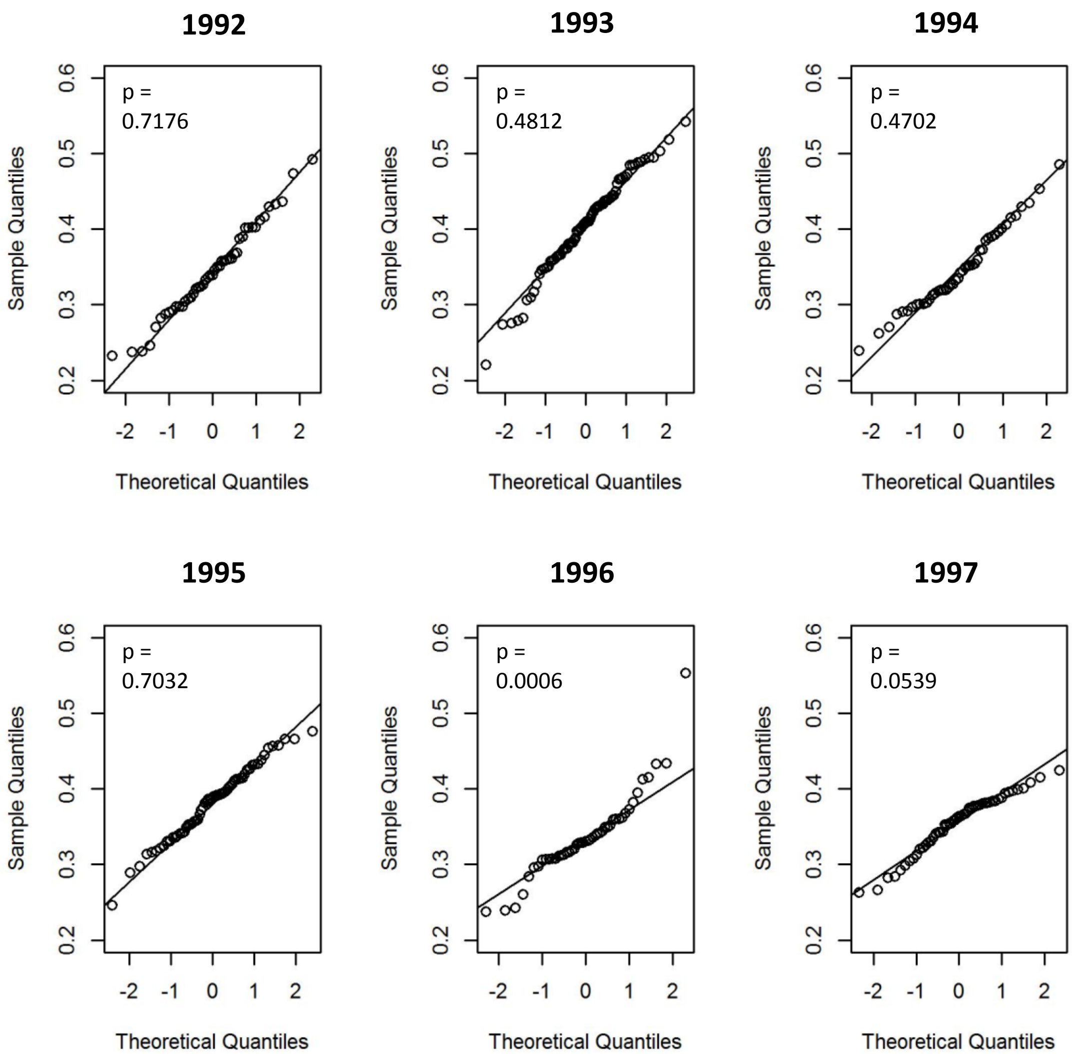


Figure A2-4. Examination of data and check against normal distribution of FW1 for Andreafsky River brood years 1992-1997. P-values listed are for Shapiro-Wilks test for normality.

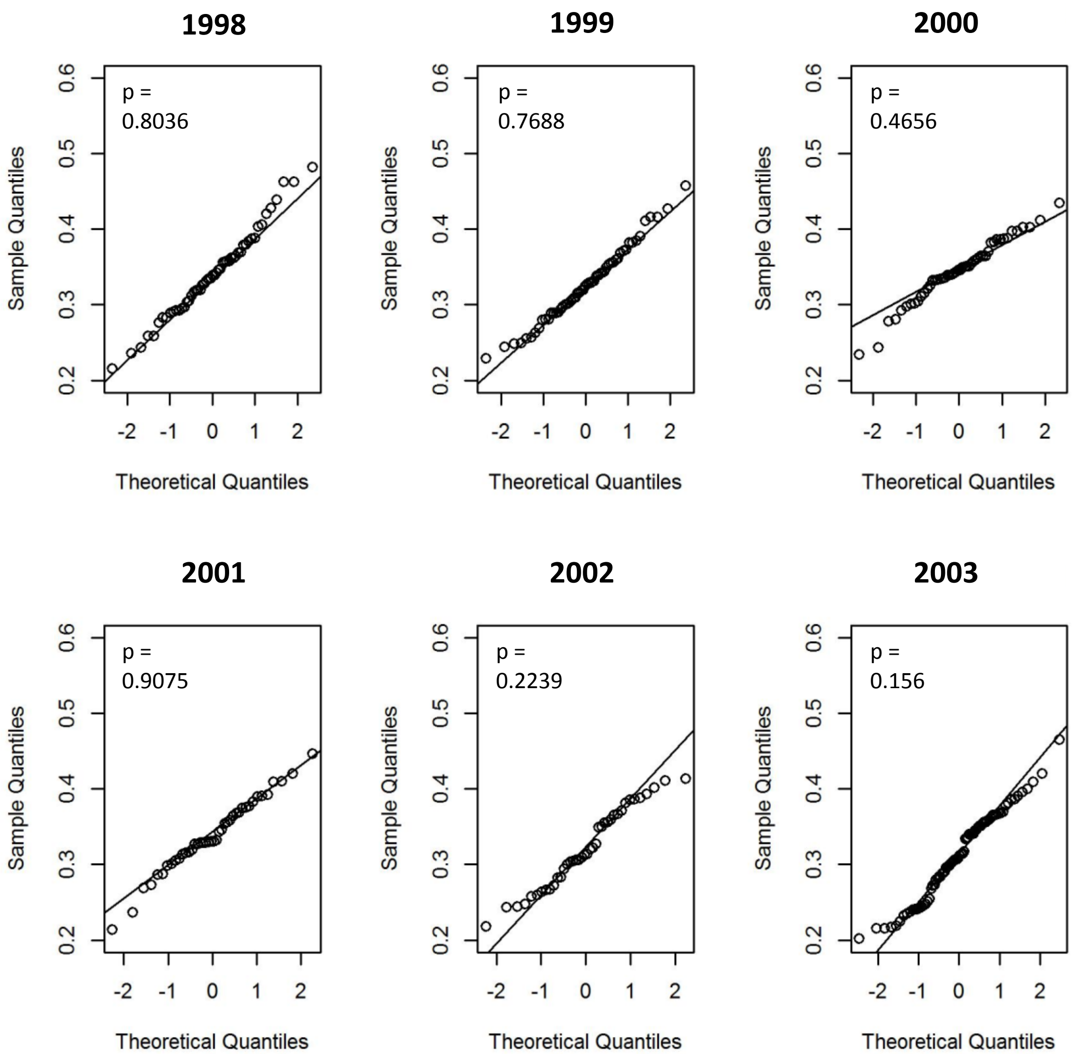


Figure A2-5. Examination of data and check against normal distribution of FW1 for Andreafsky River brood years 1998-2003. P-values listed are for Shapiro-Wilks test for normality.

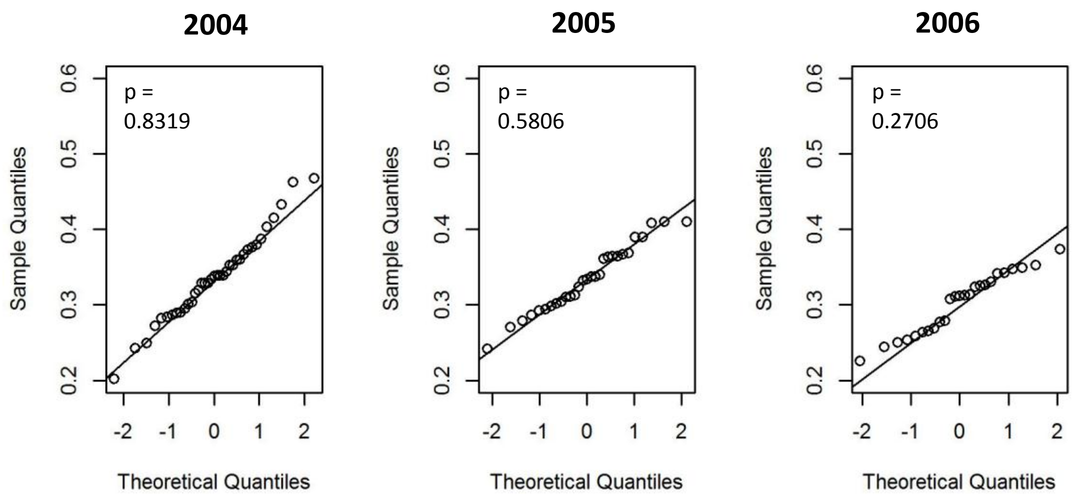


Figure A2-6. Examination of data and check against normal distribution of FW1 for Andreafsky River brood years 2004-2006. P-values listed are for Shapiro-Wilks test for normality.

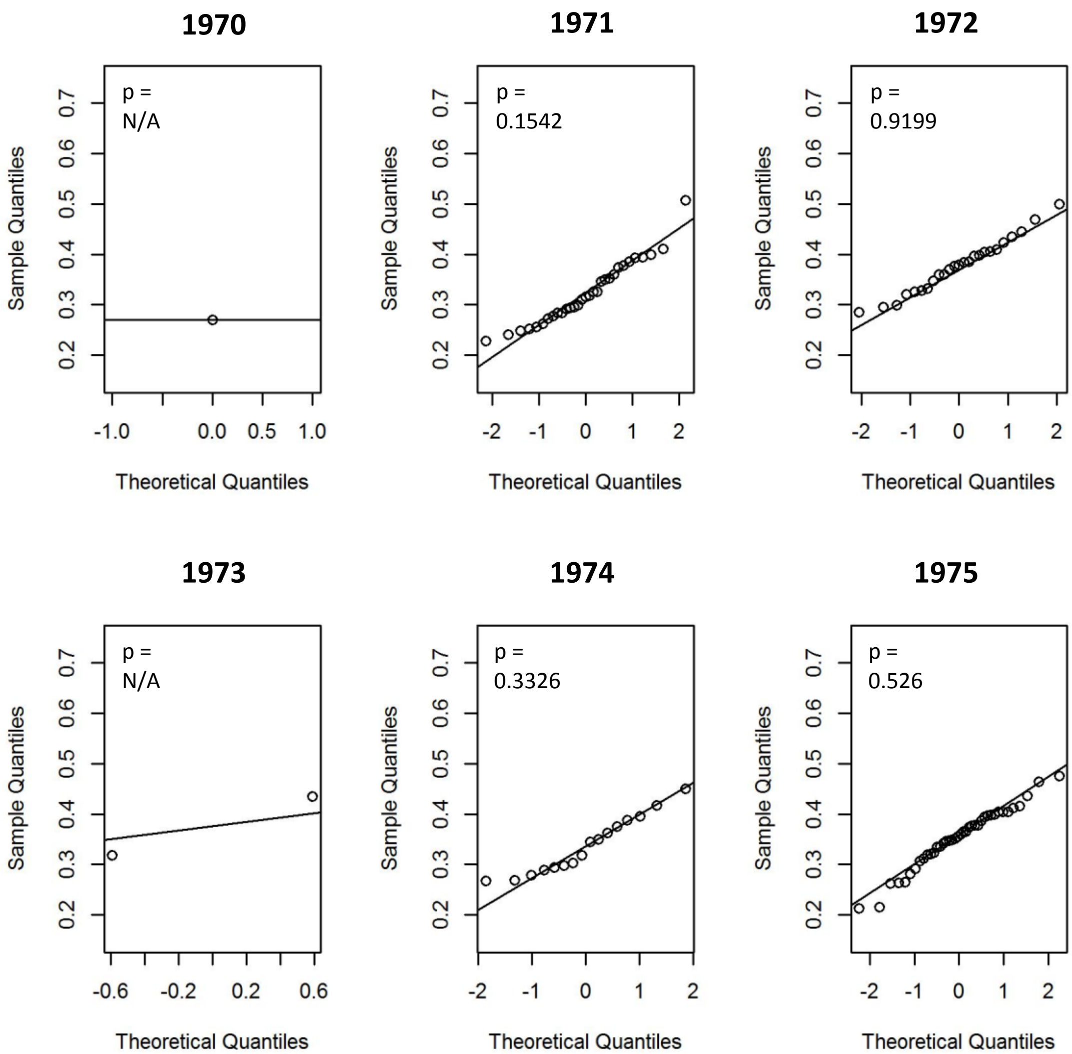


Figure A2-7. Examination of data and check against normal distribution of FW1 for Kogrukluk River brood years 1970-1975. P-values listed are for Shapiro-Wilks test for normality.

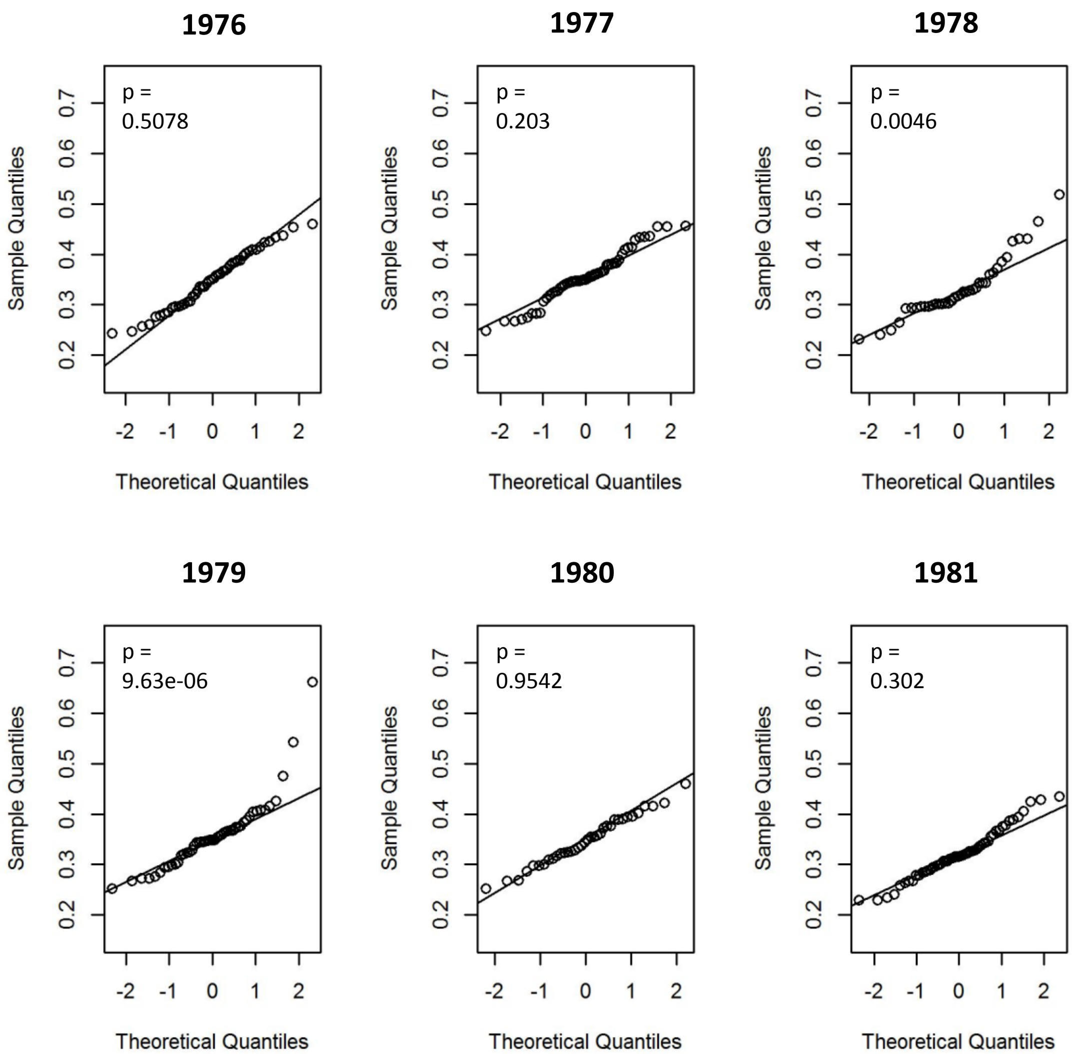


Figure A2-8. Examination of data and check against normal distribution of FW1 for Kogrukluk River brood years 1976-1981. P-values listed are for Shapiro-Wilks test for normality.

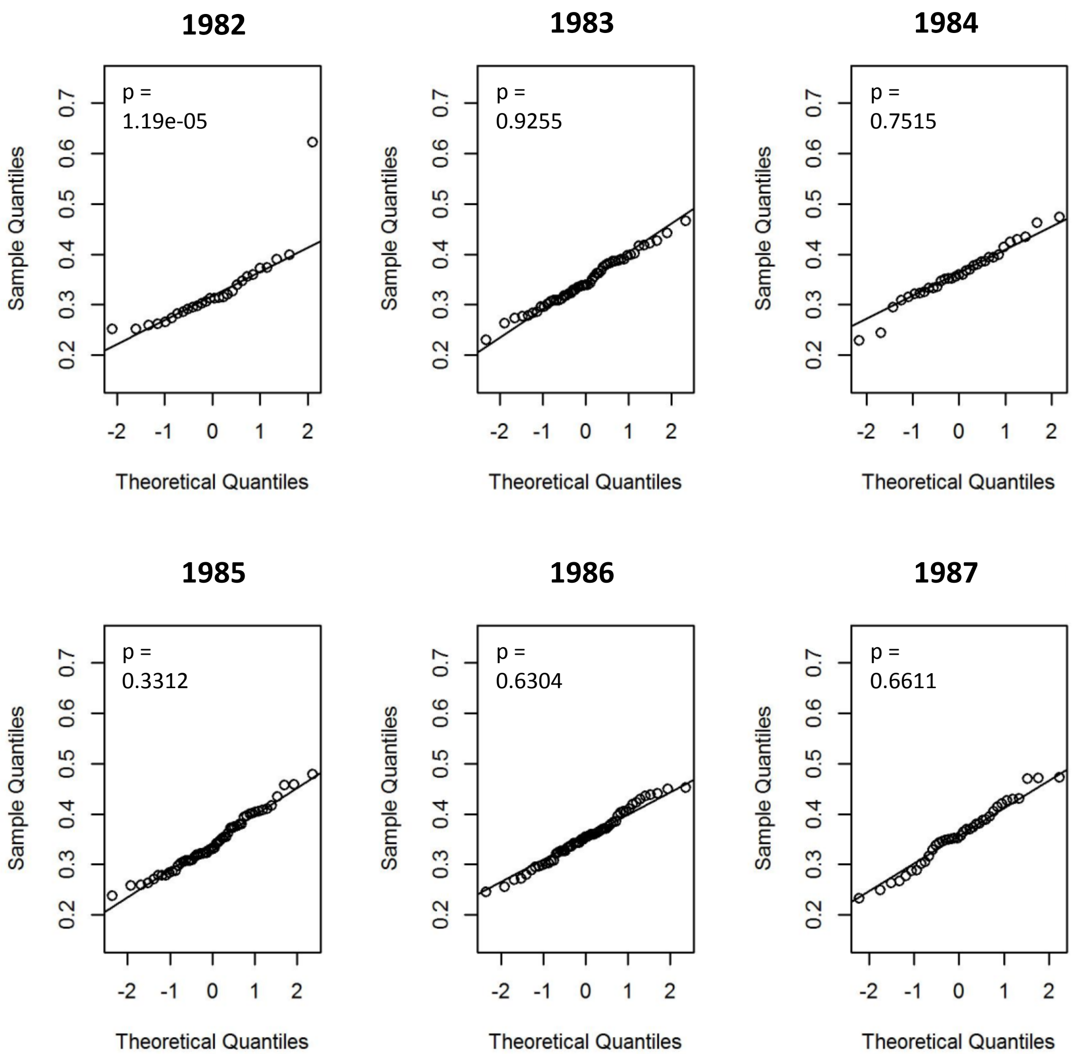


Figure A2-9. Examination of data and check against normal distribution of FW1 for Kogrukluk River brood years 1982-1987. P-values listed are for Shapiro-Wilks test for normality.

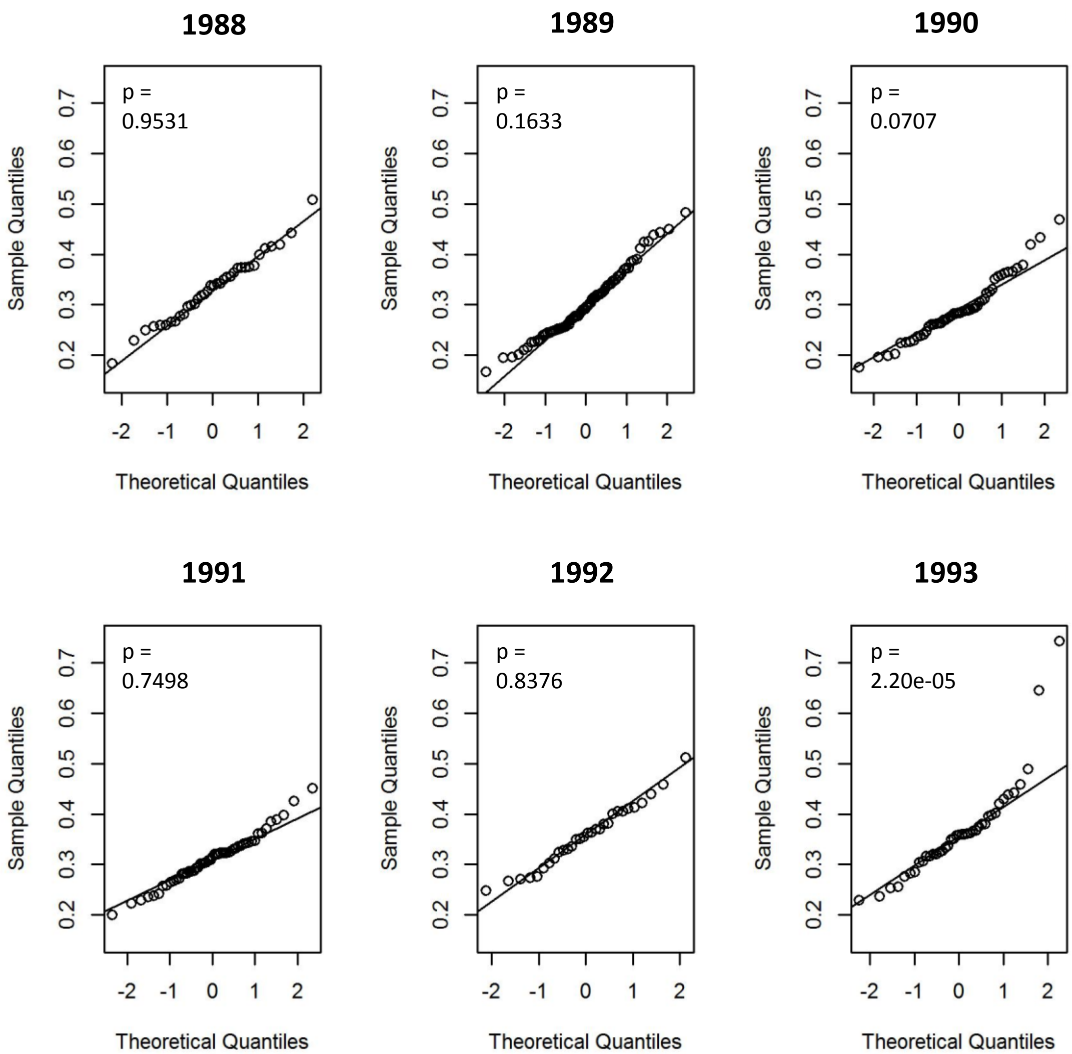


Figure A2-10. Examination of data and check against normal distribution of FW1 for Kogrukluk River brood years 1988-1993. P-values listed are for Shapiro-Wilks test for normality.

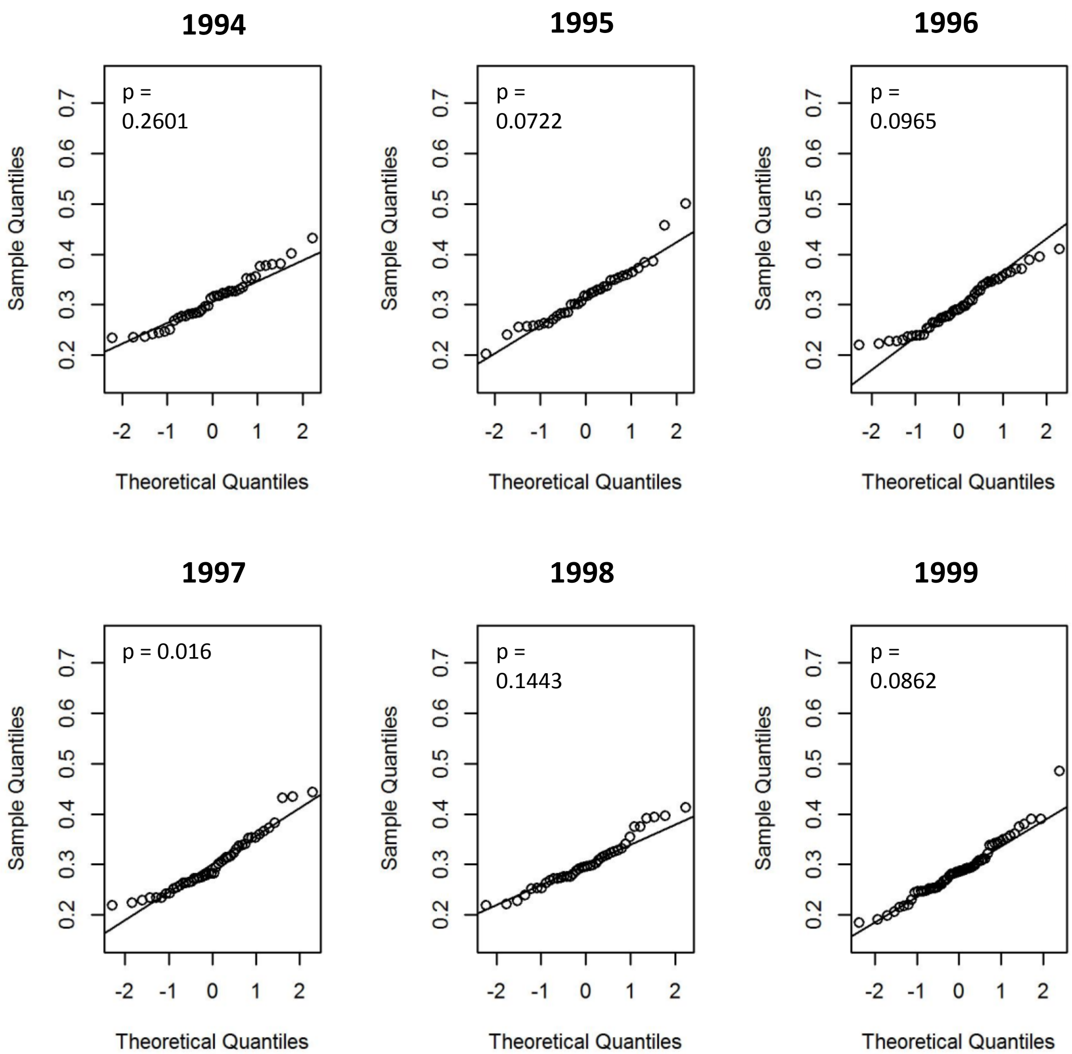


Figure A2-11. Examination of data and check against normal distribution of FW1 for Kogrukluk River brood years 1994-1999. P-values listed are for Shapiro-Wilks test for normality.

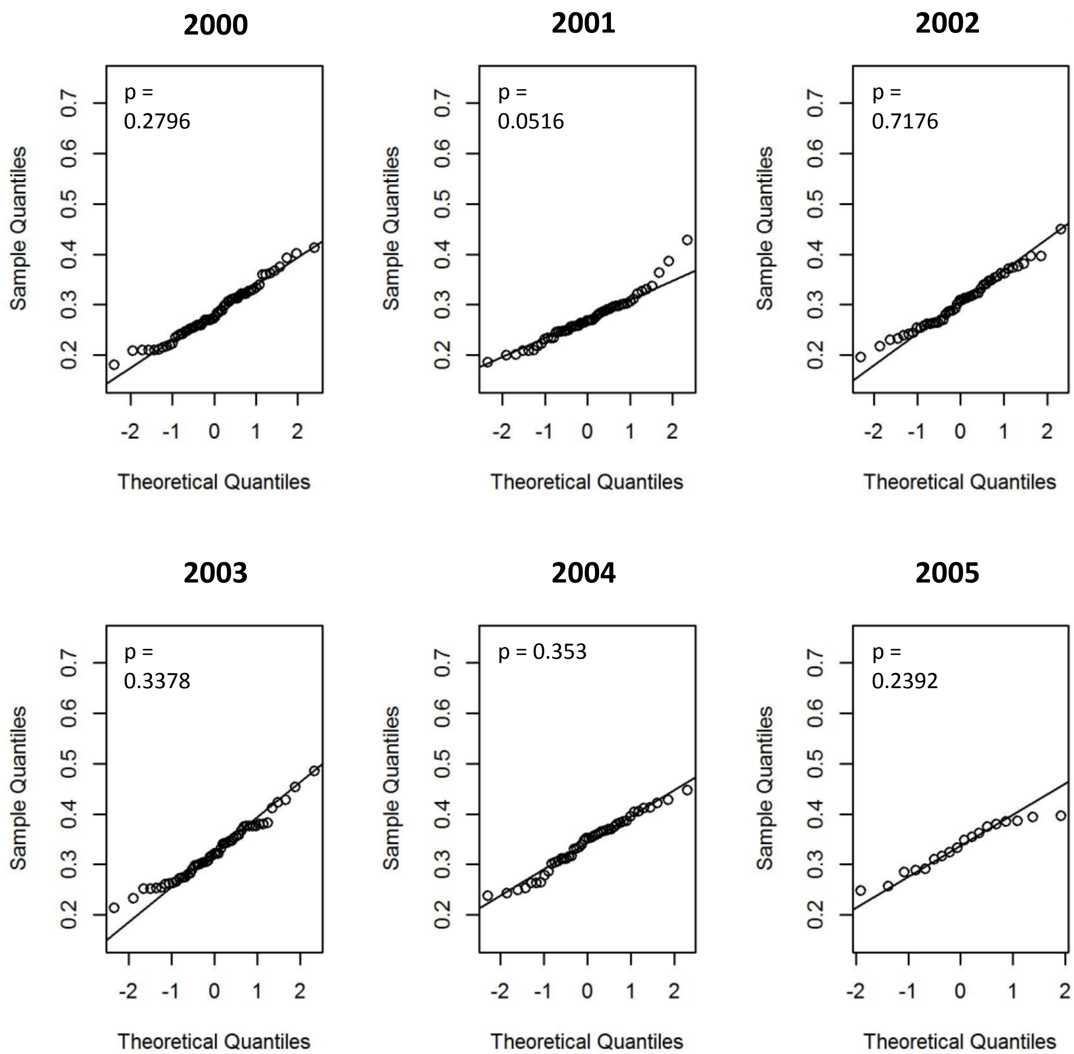


Figure A2-12. Examination of data and check against normal distribution of FW1 for Kogrukluk River brood years 2000-2005. P-values listed are for Shapiro-Wilks test for normality.